Chemistry Live Complete Textbook in full

Organic Chemistry Ii - Lab (St Joseph's University)

Textbook – Worked Solutions

Chapter 4 – The Periodic Table

4.1 (l)

In 100 atoms of gallium there are:

60 atoms of mass 69 = 60 × 69 = 4140

40 atoms of mass 71 = 40 × 71 = 2840

Total mass of 100 atoms = 6980

Average mass of 1 atom = 69.8

Answer: Relative atomic mass of gallium = 69.8

4.5 (b) (iii)

In 100 atoms of copper there are:

70 atoms of mass 63 = 70 × 63 = 4410

30 atoms of mass 65 = 30 × 65 = 1950

Total mass of 100 atoms = 6360

Average mass of 1 atom = 63.6

Answer: Relative atomic mass of copper = 63.6

Chapter 9 - The Mole Concept

9.1

Since a sulfur atom (A_r = 32) weighs twice as much as an oxygen atom (A_r = 16), 32 g of sulfur atoms and 16 g of oxygen atoms both contain the same number of atoms.
Answer: 32 g

9.2

(a) 1 mole of H atoms = 1 g
1 mole of H_2 molecules = $2 \times 1 = 2$ g.
(b) 1 mole of N atoms = 14 g
1 mole of N_2 molecules = $2 \times 14 = 28$ g
(c) 1 mole of O atoms = 16 g
1 mole of O_2 molecules = $2 \times 16 = 32$ g
(d) 1 mole of Cl atoms = 35.5 g
1 mole of Cl_2 molecules = $2 \times 35.5 = 71$ g
(e) 1 mole of F atoms = 19 g
1 mole of F_2 molecules = $2 \times 19 = 38$ g
(f) 1 mole of Br atoms = 80 g
1 mole of Br_2 molecules = $2 \times 80 = 160$ g

9.3 **NOTE Relative Molecular Mass has NO units!**

(a) Relative Molecular Mass H_2SO_4 $= (2 \times 1) + 32 + (4 \times 16)$
$= 2 + 32 + 64$
$= 98$

(b) Relative Molecular Mass CO_2 $= 12 + (2 \times 16)$
$= 12 + 32$
$= 44$

(c) Relative Molecular Mass HI $= 1 + 127$
$= 128$

(d) Relative Molecular Mass NaCl $= 23 + 35.5$
$= 58.5$

(e) Relative Molecular Mass $AlBr_3$ $= 27 + (3 \times 80)$
$= 27 + 240$
$= 267$

(f) Relative Molecular Mass SO_2 $= 32 + (2 \times 16)$
$= 32 + 32$
$= 64$

(g) Relative Molecular Mass $CuCO_3 = 63.5 + 12 + (3 \times 16)$
$= 63.5 + 12 + 48$
$= 123.5$

(h) Relative Molecular Mass $Na_2CO_3 = (2 \times 23) + 12 + (3 \times 16)$
$= 46 + 12 + 48$
$= 106$

(i) Relative Molecular Mass $NaOH = 23 + 16 + 1$
$= 40$

(j) Relative Molecular Mass $NO_3^- = 14 + (3 \times 16)$
$= 14 + 48$
$= 62$

(k) Relative Molecular Mass $Na_2CO_3.10\ H_2O = (2 \times 23) + 12 + (3 \times 16) + (10 \times 18)$
$= 46 + 12 + 48 + 180$
$= 286$

(l) Relative Molecular Mass $Ca_3(PO_4)_2 = (3 \times 40) + (2 \times 31) + (8 \times 16)$
$= 120 + 62 + 128$
$= 310$

(m) Relative Molecular Mass $FeSO_4.7H_2O = 56 + 32 + (4 \times 16) + (7 \times 18)$
$= 56 + 32 + 64 + 126$
$= 278$

(n) Relative Molecular Mass $C_{12}H_{22}O_{11} = (12 \times 12) + (22 \times 1) + (11 \times 16)$
$= 144 + 22 + 176$
$= 342$

<u>9.4</u>

(a)

$$\text{Number of moles of Na} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{69}{23} = 3$$

(b)

$$\text{Number of moles of Zn} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{162.5}{65} = 2.5$$

(c)

$$\text{Number of moles of Cr} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{6.5}{52} = 0.125$$

(d)

$$\text{Number of moles of Cu} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{254}{63.5} = 4$$

(e)

$$\text{Number of moles of Pb} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{31.05}{207} = 0.15$$

9.5

(a) Relative Molecular Mass O_2 $= 2 \times 16 = 32$

$$\text{Number of moles of } O_2 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{192}{32} = 6$$

(b) Relative Molecular Mass Br_2 $= 2 \times 80 = 160$

$$\text{Number of moles of } Br_2 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{4}{160} = 0.025$$

(c) Relative Molecular Mass N_2 $= 2 \times 14 = 28$

$$\text{Number of moles of } N_2 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{140}{28} = 5$$

(d) Relative Molecular Mass CO $= 12 + 16 = 28$

$$\text{Number of moles of CO} = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{56}{28} = 2$$

(e) Relative Molecular Mass C_2H_4 $= (2 \times 12) + (4 \times 1) = 24 + 4 = 28$

$$\text{Number of moles of } C_2H_4 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{0.7}{28} = 0.025$$

(f) Relative Molecular Mass SO_4^{2-} = 32 + (4 × 16) = 32 + 64 = 96

$$\text{Number of moles of } SO_4^{2-} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{9.6}{96} = 0.1$$

<u>9.6</u>

(a) 1 mole of C contains 6×10^{23} atoms
0.54 mole of C contains $0.54 \times 6 \times 10^{23}$ atoms
= 3.24×10^{23} atoms

(b) 1 mole of Sn contains 6×10^{23} atoms
1.24 moles of Sn contain $1.24 \times 6 \times 10^{23}$ atoms
= 7.44×10^{23} atoms

(c) 1 mole of Zn contains 6×10^{23} atoms
6.2 moles of Zn contain $6.2 \times 6 \times 10^{23}$ atoms
= 3.72×10^{24} atoms

(d) 1 mole of Fe contains 6×10^{23} atoms
200 moles of Fe contain $200 \times 6 \times 10^{23}$ atoms
= 1.2×10^{26} atoms

(e) 1 mole of Ag contains 6×10^{23} atoms
5×10^{-5} mole of Ag contains $5 \times 10^{-5} \times 6 \times 10^{23}$ atoms
= 3×10^{19} atoms

<u>9.7</u>

(a) 1 mole of Al contains 6×10^{23} atoms
i.e. 27 g of Al contain 6×10^{23} atoms

$$1 \text{ g of Al contains } \frac{6 \times 10^{23}}{27} \text{ atoms}$$

$$54 \text{ g of Al contain } \frac{54 \times 6 \times 10^{23}}{27} \text{ atoms}$$

$$= 1.2 \times 10^{24} \text{ atoms}$$

(b) 1 mole of Ag contains 6×10^{23} atoms
i.e. 108 g of Ag contain 6×10^{23} atoms

1 g of Ag contains $\dfrac{6 \times 10^{23}}{108}$ atoms

168 g of Ag contain $\dfrac{168 \times 6 \times 10^{23}}{108}$ atoms

$= 9.33 \times 10^{23}$ atoms

(c) 1 mole of Mg contains 6×10^{23} atoms
i.e. 24 g of Mg contain 6×10^{23} atoms

1 g of Mg contains $\dfrac{6 \times 10^{23}}{24}$ atoms

96 g of Mg contain $\dfrac{96 \times 6 \times 10^{23}}{24}$ atoms

$= 2.4 \times 10^{24}$ atoms

(d) 1 mole of Fe contains 6×10^{23} atoms
i.e. 56 g of Fe contain 6×10^{23} atoms

1 g of Fe contains $\dfrac{6 \times 10^{23}}{56}$ atoms

3.36 g of Fe contain $\dfrac{3.36 \times 6 \times 10^{23}}{56}$ atoms

$= 3.6 \times 10^{22}$ atoms

(e) 1 mole of C contains 6×10^{23} atoms
i.e. 12 g of C contain 6×10^{23} atoms

1 g of C contains $\dfrac{6 \times 10^{23}}{12}$ atoms

0.12 g of C contains $\dfrac{0.12 \times 6 \times 10^{23}}{12}$ atoms

$= 6 \times 10^{21}$ atoms

9.8

(a) 6×10^{23} atoms of C = 1 mole

1 atom of C = $\dfrac{1}{6 \times 10^{23}}$ mole

5×10^{24} atoms of C = $\dfrac{5 \times 10^{24}}{6 \times 10^{23}}$ mole

= 8.33 moles

(b) 6×10^{23} atoms of Zn = 1 mole

1 atom of Zn = $\dfrac{1}{6 \times 10^{23}}$ mole

8×10^{26} atoms of Zn = $\dfrac{8 \times 10^{26}}{6 \times 10^{23}}$ mole

$= 1.33 \times 10^{3}$ moles

(c) 6×10^{23} atoms of Au = 1 mole

1 atom of Au = $\dfrac{1}{6 \times 10^{23}}$ mole

$$2.6 \times 10^{12} \text{ atoms of Au} = \frac{2.6 \times 10^{12}}{6 \times 10^{23}} \text{ mole}$$

$$= 4.33 \times 10^{-12} \text{ mole}$$

(d) 6×10^{23} atoms of Ag = 1 mole

$$1 \text{ atom of Ag} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$9.8 \times 10^{27} \text{ atoms of Ag} = \frac{9.8 \times 10^{27}}{6 \times 10^{23}} \text{ mole}$$

$$= 1.63 \times 10^{4} \text{ moles}$$

(e) 6×10^{23} atoms of Mg = 1 mole

$$1 \text{ atom of Mg} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$1.3 \times 10^{6} \text{ atoms of Mg} = \frac{1.3 \times 10^{6}}{6 \times 10^{23}} \text{ mole}$$

$$= 2.17 \times 10^{-18} \text{ mole}$$

Chapter 10 - Properties of Gases

10.1

Given	s.t.p.
$V_1 = 75\ cm^3$	$V_2 = ?$
$p_1 = 900\ kPa$	$p_2 = 100\ kPa$
$T_1 = 20\ °C + 273 = 293\ K$	$T_2 = 273K$

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\frac{900 \times 75}{293} = \frac{100 \times V_2}{273}$$

$$\Rightarrow V_2 = \frac{900 \times 75 \times 273}{293 \times 100}$$

$$= 628.92\ cm^3$$

10.2

Old	New
$V_1 = 100\ cm^3$	$V_2 = 55\ cm^3$
$p_1 = 1 \times 10^5\ Pa$	$p_2 = ?$
$T_1 = T_2$	

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$1 \times 10^5 \times 100 = p_2 \times 55$$

$$\Rightarrow p_2 = \frac{1 \times 10^5 \times 100}{55}$$

$$= 181818.18\ Pa$$
$$\approx 1.8 \times 10^5\ Pa$$

10.3

<u>Old</u>	<u>New</u>
$V_1 = 5$ L	$V_2 = ?$
$p_1 = 9.2 \times 10^4$ Nm^{-2}	$p_2 = 1.01 \times 10^5$ Nm^{-2}
$T_1 = T_2$	

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$9.2 \times 10^4 \times 5 = 1.01 \times 10^5 \times V_2$$

$$\Rightarrow V_2 = \frac{9.2 \times 10^4 \times 5}{1.01 \times 10^5}$$

$$= 4.55 \text{ L}$$

10.4

<u>Old</u>	<u>New</u>
$V_1 = 2500$ L	$V_2 = ?$
$p_1 = 500$ kPa	$p_2 = 100$ kPa
$T_1 = 100$ °C + 273 = 373 K	$T_2 = 20$ °C + 273 = 293 K

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\frac{500 \times 2500}{373} = \frac{100 \times V_2}{293}$$

$$\Rightarrow V_2 = \frac{500 \times 2500 \times 293}{373 \times 100}$$

$$= 9819.03 \text{ L}$$

10.5

	Nitrogen	+	Hydrogen	º	Ammonia	
	N_2	+	H_2	º	NH_3	
	50 cm^3		150 cm^3		100 cm^3	
Ratio	**1**	**:**	**3**	**:**	**2**	

The volume of the reacting gases and the volume of the gaseous product are in simple whole number ratios as expected from Gay-Lussac's Law of Combining Volumes.

10.6

(a) Rel molecular mass NH_3 = 14 + (3 × 1) = 14 + 3 = 17
i.e. 1 mole of NH_3 = 17 g
17 g of NH_3 occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{17}{22.4} = 0.76 \text{ g/L}$$

(b) Rel molecular mass N_2 = 2 × 14 = 28
i.e. 1 mole of N_2 = 28 g
28 g of N_2 occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{28}{22.4} = 1.25 \text{ g/L}$$

(c) Rel molecular mass Cl_2 = 2 × 35.5 = 71
i.e. 1 mole of Cl_2 = 71 g
71 g of Cl_2 occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{71}{22.4} = 3.17 \text{ g/L}$$

(d) Rel molecular mass CH_4 = 12 + (4 × 1) = 12 + 4 = 16
i.e. 1 mole of CH_4 = 16g
16 g of CH_4 occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{16}{22.4} = 0.71 \text{ g/L}$$

(e) Rel molecular mass O_2 = 2 × 16 = 32
i.e. 1 mole of O_2 = 32 g
32 g of O_2 occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{32}{22.4} = 1.43 \text{ g/L}$$

(f) Rel molecular mass O_3 = 3 × 16 = 48
i.e. 1 mole of O_3 = 48 g
48 g of O_3 occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{48}{22.4} = 2.14 \text{ g/L}$$

<u>10.7</u>

200 cm^3 have a mass of 1 g

1 cm^3 has a mass of $\frac{1}{200}$ g

22,400 cm^3 have a mass of $\frac{22{,}400}{200}$ g

= 112 g

i.e. 22.4 L of the gas have a mass of 112g
⇒ Relative molecular mass of gas = 112

10.8

(d)

Laboratory	s.t.p.
$V_1 = 332\ cm^3$	$V_2 = ?$
$p_1 = 1.2 \times 10^5$ Pa	$p_2 = 1 \times 10^5$ Pa
$T_1 = 100\ °C + 273 = 373$ K	$T_2 = 273$ K

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\frac{1.2 \times 10^5 \times 332}{373} = \frac{1 \times 10^5 \times V_2}{273}$$

$$\Rightarrow \quad V_2 = \frac{1.2 \times 10^5 \times 332 \times 273}{373 \times 1 \times 10^5}$$

$$= 291.59\ cm^3$$

Mass of condensed liquid = 109.72 - 108.41 = 1.31 g

At s.t.p. 291.59 cm^3 of the vapour have a mass of 1.31g

1 cm^3 of the vapour has a mass of $\frac{1.31}{291.59}$ g

$\Rightarrow$ 22,400 cm^3 of the vapour have a mass of $\frac{22{,}400 \times 1.31}{291.59}$

= 100.63 g

i.e. Relative molecular mass of liquid = 100.63

10.10 Relative molecular mass $O_2 = 2 \times 16 = 32$

This problem can be solved using either:
(a) Ideal Gas Equation **pV = nRT**

P = 20 kPa = 20,000 Pa

V = ?

$$n = \text{number of moles} = \frac{\text{Mass in grams}}{\text{Rel molecular mass}} = \frac{20}{32} = 0.625$$

$R = 8.31\ J\ mol^{-1}\ K^{-1}$
$T = 25\ ^oC = 25 + 273 = 298\ K$

pV = nRT

$$V = \frac{nRT}{p} = \frac{0.625 \times 8.31 \times 298}{20{,}000} = 0.0774\ m^3 = 0.0774 \times 1000\ L = 77.4\ L$$

OR

(b) Combined Gas Law $\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$

Given	s.t.p.
$V_1 = ?\ cm^3$	$V_2 = 22.4\ L$
$p_1 = 20\ kPa$	$p_2 = 101.3\ kPa$
$T_1 = 25\ °C + 273 = 298\ K$	$T_2 = 273\ K$

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\frac{20 \times V_1}{298} = \frac{101.3 \times 22.4}{273}$$

$$\Rightarrow\ V_1 = \frac{101.3 \times 22.4 \times 298}{273 \times 20}$$

$= 123.85 \text{ L}$

1 mole of O_2 occupies 123.85 L under the above conditions
i.e. 32 g of O_2 occupies 123.85 L

$$1 \text{ g of } O_2 \text{ occupies } \frac{123.85}{32} \text{ L}$$

$$20 \text{ g of } O_2 \text{ occupies } \frac{123.85 \times 20}{32} \text{ L}$$

$$= 77.4 \text{ L}$$

<u>10.11</u>

$p = 101.325 \text{ kPa} = 101{,}325 \text{ Pa}$
$V = 46 \text{ cm}^3 = 46 \times 10^{-6} \text{ m}^3$
$n = ?$
$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
$T = 100 \text{ °C} + 273 = 373 \text{ K}$

$pV = nRT$

$$n = \frac{pV}{RT}$$

$$= \frac{101{,}325 \times 46 \times 10^{-6}}{8.31 \times 373}$$

$$= 1.504 \times 10^{-3} \text{ moles}$$

i.e. 1.504×10^{-3} moles $= 0.16$ g

$$1 \text{ mole of liquid} = \frac{0.16}{1.504 \times 10^{-3}}$$

$$= 106.38$$

i.e. Relative molecular mass of liquid ≈ 106

10.12

p = 100.5 kPa = 100,500 Pa
V = 127 cm^3 = 127 × 10^{-6} m^3
n = ?
R = 8.31 J mol^{-1} K^{-1}
T = 98 °C + 273 = 371 K

$$pV = nRT$$

$$n = \frac{pV}{RT}$$

$$= \frac{100{,}500 \times 127 \times 10^{-6}}{8.31 \times 371}$$

$$= 4.14 \times 10^{-3} \text{ mole}$$

i.e. 4.14×10^{-3} mole = 0.495 g

$$1 \text{ mole of liquid} = \frac{0.495}{4.14 \times 10^{-3}}$$

$$= 119.57$$

i.e. Relative molecular mass of liquid ≈ 120

Chapter 11 - Stoichiometry

11.1

(a) Relative molecular mass MgO = 24 + 16 = 40

$$\% \text{ Mg} = \frac{24}{40} \times 100 = 60\%$$

$$\% \text{ O} = \frac{16}{40} \times 100 = 40\%$$

(b) Relative molecular mass Al_2O_3 = (2 × 27) + (3 × 16) = 54 + 48 = 102

$$\% \text{ Al} = \frac{54}{102} \times 100 = 52.94\%$$

$$\% \text{ O} = \frac{48}{102} \times 100 = 47.06\%$$

(c) Relative molecular mass $MgSO_4$ = 24 + 32 + (4 × 16) = 24 + 32 + 64 = 120

$$\% \text{ Mg} = \frac{24}{120} \times 100 = 20\%$$

$$\% \text{ S} = \frac{32}{120} \times 100 = 26.67\%$$

$$\% \text{ O} = \frac{64}{120} \times 100 = 53.33\%$$

(d) Relative molecular mass $CaCO_3 = 40 + 12 + (3 \times 16) = 40 + 12 + 48 = 100$

$$\% \text{ Ca} = \frac{40}{100} \times 100 = 40\%$$

$$\% \text{ C} = \frac{12}{100} \times 100 = 12\%$$

$$\% \text{ O} = \frac{48}{100} \times 100 = 48\%$$

(e) Relative molecular mass $NaCl = 23 + 35.5 = 58.5$

$$\% \text{ Na} = \frac{23}{58.5} \times 100 = 39.32\%$$

$$\% \text{ Cl} = \frac{35.5}{58.5} \times 100 = 60.68\%$$

(f) Relative molecular mass $(NH_4)_2SO_4 = (2 \times 14) + (8 \times 1) + 32 + (4 \times 16)$
$= 28 + 8 + 32 + 64$
$= 132$

$$\% \text{ N} = \frac{28}{132} \times 100 = 21.21\%$$

$$\% \text{ H} = \frac{8}{132} \times 100 = 6.06\%$$

$$\% \text{ S} = \frac{32}{132} \times 100 = 24.24\%$$

$$\% \text{ O} = \frac{64}{132} \times 100 = 48.48\%$$

(g) Relative molecular mass $(COOH)_2 = (2 \times 12) + (4 \times 16) + (2 \times 1)$
$= 24 + 64 + 2$
$= 90$

$$\% C = \frac{24}{90} \times 100 = 26.67\%$$

$$\% H = \frac{2}{90} \times 100 = 2.22\%$$

$$\% O = \frac{64}{90} \times 100 = 71.11\%$$

(h) Relative molecular mass $CH_3COOH = 12 + (3 \times 1) + 12 + (2 \times 16) + 1$
$= 12 + 3 + 12 + 32 + 1$
$= 60$

$$\% C = \frac{24}{60} \times 100 = 40\%$$

$$\% H = \frac{4}{60} \times 100 = 6.67\%$$

$$\% O = \frac{32}{60} \times 100 = 53.33\%$$

(i) Relative molecular mass $Pb(NO_3)_2 = 207 + (2 \times 14) + (6 \times 16)$
$= 207 + 28 + 96$
$= 331$

$$\% Pb = \frac{207}{331} \times 100 = 62.54\%$$

$$\% N = \frac{28}{331} \times 100 = 8.46\%$$

$$\% O = \frac{96}{331} \times 100 = 29\%$$

(j) Relative molecular mass $KHCO_3 = 39 + 1 + 12 + (3 \times 16)$
$= 39 + 1 + 12 + 48$
$= 100$

$$\% K = \frac{39}{100} \times 100 = 39\%$$

$$\% C = \frac{12}{100} \times 100 = 12\%$$

$$\% H = \frac{1}{100} \times 100 = 1\%$$

$$\% O = \frac{48}{100} \times 100 = 48\%$$

<u>11.2</u>

Relative molecular mass $NH_4NO_3 = 14 + (1 \times 4) + 14 + (16 \times 3)$
$= 14 + 4 + 14 + 48$
$= 80$

$$\% N = \frac{28}{80} \times 100 = 35\ \%$$

Relative molecular mass $(NH_4)_2SO_4 = (14 \times 2) + (1 \times 8) + 32 + (16 \times 4)$
$= 28 + 8 + 32 + 64$
$= 132$

$$\% N = \frac{28}{132} \times 100 = 21.21\ \%$$

Relative molecular mass $(NH_2)_2CO = (14 \times 2) + (1 \times 4) + 12 + 16$
$= 28 + 4 + 12 + 16$
$= 60$

$$\% N = \frac{28}{60} \times 100 = 46.67\ \%$$

Urea $(NH_2)_2CO$ contains the highest % of N.

11.3

C_6H_6 :- Empirical formula = CH
$C_2H_4O_2$:- Empirical formula = CH_2O
$C_3H_6O_3$:- Empirical formula = CH_2O

11.4

Molecular Formula = empirical formula × n

$$60 = (N_2H_4CO) \times n$$
$$60 = [(14 \times 2) + (1 \times 4) + 12 + 16]\ n$$
$$60 = (28 + 4 + 12 + 16)\ n$$
$$60 = 60n$$
$$n = 1$$

⇒ Molecular Formula = $(N_2H_4CO) \times 1$
= N_2H_4CO

11.5

(a)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 3.31)**
Nitrogen	47	$\frac{47}{14} = 3.36$	$\frac{3.36}{3.31} = 1$
Oxygen	53	$\frac{53}{16} = 3.31$	$\frac{3.31}{3.31} = 1$

i.e. Empirical formula = NO

(b)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 2.18)**
Nitrogen	30.5	$\frac{30.5}{14} = 2.18$	$\frac{2.18}{2.18} = 1$
Oxygen	69.5	$\frac{69.5}{16} = 4.34$	$\frac{4.34}{2.18} = 2$

i.e. Empirical formula = NO_2

(c)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 6.25)**
Carbon	75	$\frac{75}{12} = 6.25$	$\frac{6.25}{6.25} = 1$
Hydrogen	25	$\frac{25}{1} = 25$	$\frac{25}{6.25} = 4$

i.e. Empirical formula = CH_4

(d)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 7.14)**
Carbon	85.7	$\frac{85.7}{12} = 7.14$	$\frac{7.14}{7.14} = 1$
Hydrogen	14.3	$\frac{14.3}{1} = 14.3$	$\frac{14.3}{7.14} = 2$

i.e. Empirical formula = CH_2

(e)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 0.62)**
Iron	34.5	$\frac{34.5}{56} = 0.62$	$\frac{0.62}{0.62} = 1$
Chlorine	65.5	$\frac{65.5}{35.5} = 1.85$	$\frac{1.85}{0.62} = 3$

i.e. Empirical formula = $FeCl_3$

(f)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 7.7)**
Carbon	92.3	$\frac{92.3}{12} = 7.69$	$\frac{7.69}{7.7} = 1$
Hydrogen	7.7	$\frac{7.7}{1} = 7.7$	$\frac{7.7}{7.7} = 1$

i.e. Empirical formula = CH

(g)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 1.25)**
Sulphur	40	$\frac{40}{32} = 1.25$	$\frac{1.25}{1.25} = 1$
Oxygen	60	$\frac{60}{16} = 3.75$	$\frac{3.75}{1.25} = 3$

i.e. Empirical formula = SO_3

(h)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 1.56)**
Sulphur	50	$\frac{50}{32} = 1.56$	$\frac{1.56}{1.56} = 1$
Oxygen	50	$\frac{50}{16} = 3.13$	$\frac{3.13}{1.56} = 2$

i.e. Empirical formula = SO_2

(i)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 0.52)**
Potassium	40.2	$\frac{40.2}{39} = 1.03$	$\frac{1.03}{0.52} = 2$
Chromium	26.9	$\frac{26.9}{52} = 0.52$	$\frac{0.52}{0.52} = 1$
Oxygen	32.9	$\frac{32.9}{16} = 2.06$	$\frac{2.06}{0.52} = 4$

i.e. Empirical formula = K_2CrO_4

(j)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 0.68)**	**Multiply by 2 to get whole numbers.**
Potassium	26.6	$\frac{26.6}{39} = 0.68$	$\frac{0.68}{0.68} = 1$	$1 \times 2 = 2$
Chromium	35.4	$\frac{35.4}{52} = 0.68$	$\frac{0.68}{0.68} = 1$	$1 \times 2 = 2$
Oxygen	38	$\frac{38}{16} = 2.38$	$\frac{2.38}{0.68} = 3.5$	$3.5 \times 2 = 7$

i.e. Empirical formula = $K_2Cr_2O_7$

(k)

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 0.54)**
Copper	34.6	$\frac{34.6}{63.5} = 0.54$	$\frac{0.54}{0.54} = 1$
Iron	30.5	$\frac{30.5}{56} = 0.54$	$\frac{0.54}{0.54} = 1$
Sulphur	34.9	$\frac{34.9}{32} = 1.09$	$\frac{1.09}{0.54} = 2$

i.e. Empirical formula = $CuFeS_2$

11.6

Element	**Percentage**	**Percentage / Rel. At. Mass**	**Simplest ratio (divide by 0.35)**
Carbon	4.2	$\frac{4.2}{12} = 0.35$	$\frac{0.35}{0.35} = 1$
Oxygen	16.8	$\frac{16.8}{16} = 1.05$	$\frac{1.05}{0.35} = 3$
Sodium	16.1	$\frac{16.1}{23} = 0.7$	$\frac{0.7}{0.35} = 2$
Water	62.9	$\frac{62.9}{18} = 3.49$	$\frac{3.49}{0.35} = 10$

i.e. Empirical formula = $Na_2CO_3.10H_2O$

11.7

calcium + oxygen ⟶ calcium oxide
2 g 2.8 g
mass of calcium = 2 g
mass of calcium oxide = 2.8 g
⇒ mass of oxygen in calcium oxide = 2.8 - 2 = 0.8 g

$$\text{number of moles of calcium in calcium oxide} = \frac{\text{mass}}{\text{Rel. atomic mass}}$$

$$= \frac{2}{40} = 0.05$$

$$\text{number of moles of oxygen in calcium oxide} = \frac{\text{mass}}{\text{Rel. atomic mass}}$$

$$= \frac{0.8}{16} = 0.05$$

Ratio of Ca : O = 0.05 : 0.05 = 1 : 1
⇒ Empirical Formula = CaO

11.8

aluminium + oxygen ⟶ aluminium oxide
2.7 g 5.1 g
mass of aluminium = 2.7 g
mass of aluminium oxide = 5.1 g
mass of oxygen in aluminium oxide = 5.1 - 2.7 = 2.4 g

$$\text{number of moles of aluminium in aluminium oxide} = \frac{\text{mass}}{\text{Rel. atomic mass}}$$

$$= \frac{2.7}{27} = 0.1$$

$$\text{number of moles of oxygen in aluminium oxide} = \frac{\text{mass}}{\text{Rel. atomic mass}}$$

$$= \frac{2.4}{16} = 0.15$$

Ratio of Al : O = 0.1 : 0.15 = 2 : 3
⇒ Empirical Formula = Al_2O_3

11.9

$MgSO_4.xH_2O \longrightarrow MgSO_4 + xH_2O$
4.1 g 2.0 g
mass of $MgSO_4$ = 2 g
mass of $MgSO_4.xH_2O$ = 4.1g
mass of H_2O in $MgSO_4.xH_2O$ = 4.1 - 2 = 2.1 g
Rel. mol. mass $MgSO_4 = 24 + 32 + (16 \times 4)$
$= 24 + 32 + 64 = 120$
Rel. mol. mass $H_2O = (1 \times 2) + 16 = 18$

$$\text{number of moles of } MgSO_4 \text{ in } MgSO_4.xH_2O = \frac{\text{mass}}{\text{Rel. mol. mass}}$$

$$= \frac{2}{120} = 0.0167$$

$$\text{number of moles of water } MgSO_4.xH_2O = \frac{\text{mass}}{\text{Rel. mol. mass}}$$

$$= \frac{2.1}{18} = 0.1167$$

Ratio of $MgSO_4 : H_2O$ = 0.0167 : 0.1167 = 1 : 7
$\Rightarrow$ $MgSO_4.\ 7H_2O$ is the formula of the hydrated salt.
i.e. Degree of hydration = 7

11.10

$MO \longrightarrow M + \frac{1}{2}O_2$
5.3 g 4.24 g

mass of metal oxide = 5.3 g
mass of metal = 4.24 g
mass of oxygen = 5.3 - 4.24 = 1.06 g

$$\text{number of moles of } O_2 = \frac{\text{mass}}{\text{Rel. mol. mass}}$$

$$= \frac{1.06}{16} = 0.0663$$

Since in the compound MO the ratio M : O = 1 : 1
$\Rightarrow$ number of moles of metal = 0.0663
i.e. 0.0663 moles of M = 4.24 g

$$1 \text{ mole of M} = \frac{4.24}{0.0663}$$

$$= 63.95 \approx 64$$

i.e. Relative atomic mass of M = 64

11.11

Rel. mol. mass $FeCl_3 = 56 + (35.5 \times 3)$
$= 56 + 106.5 = 162.5$

$2Fe + 3Cl_2 \longrightarrow 2FeCl_3$
$2Fe \longrightarrow 2FeCl_3$ (shortened version of equation)
2 moles $\longrightarrow$ 2 moles
2 (56) g $\longrightarrow$ 2(162.5) g
i.e. 112 g Fe $\longrightarrow$ 325 g $FeCl_3$

$$1\text{g Fe} \longrightarrow \frac{325}{112}\text{g } FeCl_3$$

$$20 \text{ g Fe} \longrightarrow \frac{20 \times 325}{112} \text{ g } FeCl_3$$

$= 58.04$ g $FeCl_3$

11.12

Rel. mol. mass $SO_2 = 32 + (16 \times 2)$
$= 32 + 32 = 64$

Rel. mol. mass $SO_3 = 32 + (16 \times 3)$
$= 32 + 48 = 80$

$2SO_2 + O_2 \longrightarrow 2SO_3$
$2SO_2 \longrightarrow 2SO_3$ (shortened version of equation)
2 moles $\longrightarrow$ 2 moles
2(64) g $\longrightarrow$ 2(80) g
i.e. 128 g $SO_2 \longrightarrow$ 160 g SO_3

$$1\text{g } SO_2 \longrightarrow \frac{160}{128} \text{ g } SO_3$$

$$200 \text{ g } SO_2 \longrightarrow \frac{200 \times 160}{128} \text{ g } SO_3$$

$= 250$ g SO_3

11.13

Rel. mol. mass $C_6H_{12}O_6$ = $(12 \times 6) + (1 \times 12) + (16 \times 6)$
= $72 + 12 + 96 = 180$

Rel. mol. mass C_2H_5OH = $(12 \times 2) + (1 \times 5) + 16 + 1$
= $24 + 5 + 16 + 1 = 46$

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH$ (shortened version of equation)

1 mole $\longrightarrow$ 2 moles

180 g $\longrightarrow$ 2 (46) g

i.e. 180 g $C_6H_{12}O_6 \longrightarrow$ 92 g C_2H_5O

$$1\text{g } C_6H_{12}O_6 \longrightarrow \frac{92}{180} \text{ g } C_2H_5OH$$

$$25 \text{ g } C_6H_{12}O_6 \longrightarrow \frac{25 \times 92}{180} \text{ g } C_2H_5OH$$

= 12.78 g C_2H_5OH

11.14

Rel. mol. mass $CaCO_3$= $40 + 12 + (16 \times 3)$
= $40 + 12 + 48 = 100$

$CaCO_3 \longrightarrow CaO + CO_2$

$CaCO_3 \longrightarrow CO_2$ (shortened version of equation)

1 mole $\longrightarrow$ 1 mole

i.e. 100 g $CaCO_3 \longrightarrow$ 22.4 L of CO_2 at s.t.p.

$$1 \text{ g } CaCO_3 \longrightarrow \frac{22.4}{100} \text{ L of } CO_2$$

$$2.5\text{g } CaCO_3 \longrightarrow \frac{2.5 \times 22.4}{100} \text{ L of } CO_2$$

= 0.56 L of CO_2

11.15

Relative mol. mass $NaHCO_3 = 23 + 1 + 12 + (16 \times 3)$
$= 23 + 1 + 12 + 48 = 84$

$2NaHCO_3 \longrightarrow CO_2 + Na_2CO_3 + 2H_2O$
$2NaHCO_3 \longrightarrow CO_2$ (shortened version of equation)
2 moles $\longrightarrow$ 1 mole
2 (84) g $\longrightarrow$ 22.4 L
i.e. 168 g $NaHCO_3 \longrightarrow$ 22.4 L of CO_2 at s.t.p.
168 g $NaHCO_3 \longrightarrow$ 22,400cm^3 CO_2 at s.t.p.

$$\frac{168}{22,400} \text{ g } NaHCO_3 \longrightarrow 1 \text{ cm}^3\ CO_2$$

$$\frac{800 \times 168}{22,400} \text{ g } NaHCO_3 \longrightarrow 800 \text{ cm}^3\ CO_2$$

= 6 g $NaHCO_3$

11.16

Relative mol. mass $H_2O_2 = (1 \times 2) + (16 \times 2)$
$= 2 + 32 = 34$

$2H_2O_2 \longrightarrow 2H_2O + O_2$
$2H_2O_2 \longrightarrow O_2$ (shortened version of equation)
2 moles $\longrightarrow$ 1 mole
2 (34) g $\longrightarrow$ 22.4 L
i.e. 68 g $H_2O_2 \longrightarrow$ 22.4 L of O_2 at s.t.p.

$$1 \text{ g } H_2O_2 \longrightarrow \frac{22.4}{68} \text{ L of } O_2$$

$$21\text{g } H_2O_2 \longrightarrow \frac{21 \times 22.4}{68} \text{ L of } O_2$$

= 6.92 L of O_2

Chapter 13 - Volumetric Analysis: Acid - Base

13.1

$$\% \text{ w/w salt} = \frac{148}{1300} \times 100 = 11.38\%$$

OR

1300 g of solution contains 148 g of salt

$$1 \text{ g contains } \frac{148}{1300} \text{ g of salt}$$

$$100 \text{ g contains } \frac{148}{1300} \times 100 = 11.38\%$$

% w/w salt = 11.38%

13.2

(a) 0.75 g / L = 0.75 × 1000 mg/L
= 750 mg/L
= 750 ppm

(b) 0.06 g / L = 0.06 × 1000 mg/L
= 60 mg/L
= 60 ppm

(c) 0.017g / 100cm^3 = 0.017 × 10 g/L
= 0.17 g/L
= 0.17 × 1000 mg/L
= 170 mg/L
= 170 ppm

(d) 0.0003g / 100cm^3 = 0.0003 × 10 g / L
= 0.003 g / L
= 0.003 × 1000 mg/L
= 3 mg / L
= 3 ppm

13.3

(a) Rel. mol mass NaOH = 23 + 16 + 1 = 40
⇒1 M NaOH = 40 g/L

(b) Rel. mol mass KOH = 39 + 16 + 1 = 56

1 M KOH = 56 g / L

$\Rightarrow$ 2 M KOH = (56×2) g / L

= 112 g/L

(c) Rel. mol mass H_2SO_4 = 2(1) + 32 + 4(16)

= 2 + 32 + 64 = 98

1 M H_2SO_4 = 98 g / L

$\Rightarrow$ 0.125 M H_2SO_4 = (0.125×98) g / L

= 12.25 g/L

(d) Rel. mol mass Na_2CO_3 = 2(23) + 12 + 3(16)

= 46 + 12 + 48 = 106

1 M Na_2CO_3 = 106 g / L

$\Rightarrow$ 0.01M Na_2CO_3 = (0.01×106) g / L

= 1.06 g/L

(e) Rel. mol mass HNO_3 = 1 + 14 + 3(16)

= 1 + 14 + 48 = 63

1 M HNO_3 = 63 g/L

$\Rightarrow$ 0.005 M HNO_3 = (0.005×63) g/L

= 0.315 g/L

13.4

(a) Rel. mol mass NaOH = 23 + 16 + 1 = 40

40 g NaOH in 1L of solution $\longrightarrow$ 1M solution

$\Rightarrow$ 1 g NaOH in 1L of solution $\longrightarrow \frac{1}{40}$ M solution

= 0.025 M

(b) Rel. mol mass H_2SO_4 = 2(1) + 32 + 4(16)

= 2 + 32 + 64 = 98

98 g H_2SO_4 in 1L of solution $\longrightarrow$ 1M solution

1g H_2SO_4 in 1L of solution $\longrightarrow \frac{1}{98}$ M solution

24g H_2SO_4 in 1L of solution $\longrightarrow \frac{24}{98}$ M solution

24g H_2SO_4 in 500cm^3 of solution $\longrightarrow \frac{24 \times 2}{98}$ M solution

= 0.49 M

(c) Rel. mol mass HCl = 1 + 35.5 = 36.5

36.5 g HCl in 1L of solution $\longrightarrow$ 1M solution

1g HCl in 1L of solution $\longrightarrow \dfrac{1}{36.5}$ M solution

22 g HCl in 1L of solution $\longrightarrow \dfrac{22}{36.5}$ M solution

22g HCl in 200cm^3 of solution $\longrightarrow \dfrac{22 \times 5}{36.5}$ M solution

= 3.01 M

(d) Rel. mol mass NaOH = 23 + 16 + 1 = 40

40 g NaOH in 1L of solution $\longrightarrow$ 1M solution

1 g NaOH in 1L of solution $\longrightarrow \dfrac{1}{40}$ M solution

20 g NaOH in 1L of solution $\longrightarrow \dfrac{20}{40}$ M solution

20g NaOH in 100cm^3 of solution $\longrightarrow \dfrac{20 \times 10}{40}$ M solution

= 5 M

(e) Rel. mol mass NaOH = 23 + 16 + 1 = 40

40 g NaOH in 1L of solution $\longrightarrow$ 1M solution

1 g NaOH in 1L of solution $\longrightarrow \dfrac{1}{40}$ M solution

4 g NaOH in 1L of solution $\longrightarrow \dfrac{4}{40}$ M solution

4 g NaOH in 1 cm^3 of solution $\longrightarrow \dfrac{4 \times 1000}{40}$ M solution

4 g NaOH in 750 cm^3 of solution $\longrightarrow \dfrac{4 \times 1000}{40 \times 750}$ M solution

= 0.13 M

13.5

(a)

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{25 \times 0.01}{1000}$$

$$= 2.5 \times 10^{-4} \text{ moles}$$

(b)

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{18 \times 2.5}{1000}$$

$$= 0.045 \text{ moles}$$

(c)

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{8.7 \times 0.5}{1000}$$

$$= 4.35 \times 10^{-3} \text{ moles}$$

(d)

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{100 \times 0.005}{1000}$$

$$= 5 \times 10^{-4} \text{ moles}$$

(e)

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{50 \times 0.09}{1000}$$

$$= 4.5 \times 10^{-3} \text{ moles}$$

13.6

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2$$

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{75 \times 0.5}{1000}$$

$$= 0.0375 \text{ moles}$$

From the balanced equation, one mole of sulfuric acid reacts with one mole of iron.
$\Rightarrow$ 0.0375 moles of Fe react
Rel. atomic mass Fe = 56
mass of Fe reacting = number of moles $\times$ rel. atomic mass
= 0.0375 $\times$ 56
= 2.1 g

13.7

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

$$\text{Number of moles of } H_2SO_4 = \frac{\text{Volume} \times \text{Molarity}}{1000}$$

$$= \frac{25 \times 2}{1000}$$

$$= 0.05 \text{ moles}$$

From the balanced equation, one mole of sulfuric acid reacts with 2 moles of sodium hydroxide.
$\Rightarrow$ (0.05 $\times$ 2) moles = 0.1 moles of NaOH react with 0.05 moles H_2SO_4

Rel. mol mass NaOH = 23 + 16 + 1 = 40
mass of NaOH reacting = number of moles $\times$ rel. mol mass
= 0.1 $\times$ 40
= 4 g

13.8

Given:-

$Vol_{dil} = 500\ cm^3$

$M_{dil} = 0.25\ M$

$Vol_{conc} = ?$

$M_{conc} = 10\ M$

$$\frac{Vol_{dil} \times M_{dil}}{\cancel{1000}} = \frac{Vol_{conc} \times M_{conc}}{\cancel{1000}}$$

$$500 \times 0.25 = Vol_{conc} \times 10$$

$$\Rightarrow Vol_{conc} = \frac{500 \times 0.25}{10}$$

$$= 12.5\ cm^3$$

i.e. $12.5\ cm^3$ of 10 M acid would have to be diluted to $500\ cm^3$.

13.9

Given:-

$Vol_{dil} = 10{,}000\ cm^3$

$M_{dil} = 1\ M$

$Vol_{conc} = ?$

$M_{conc} = 18\ M$

$$\frac{Vol_{dil} \times M_{dil}}{\cancel{1000}} = \frac{Vol_{conc} \times M_{conc}}{\cancel{1000}}$$

$$10{,}000 \times 1 = Vol_{conc} \times 18$$

$$\Rightarrow Vol_{conc} = \frac{10{,}000 \times 1}{18}$$

$$= 555.56\ cm^3$$

i.e. $555.56\ cm^3$ of 18 M acid would have to be diluted to 10 L.

13.11

(a) Balanced equation:

$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2H_2O$

Given:

$V_a = 11.5\ cm^3$

$M_a = 0.5\ M$

$n_a = 1$

$V_b = 25\ cm^3$

$M_b = ?$

$n_b = 2$

$$\underset{H_2SO_4}{\frac{V_a \times M_a}{n_a}} = \underset{NaOH}{\frac{V_b \times M_b}{n_b}}$$

$$\frac{11.5 \times 0.5}{1} = \frac{25 \times M_b}{2}$$

$$\Rightarrow M_b = \frac{11.5 \times 0.5 \times 2}{25}$$

$$= 0.46\ \text{moles / L}$$

(b) Rel. mol mass NaOH = 23 + 16 + 1 = 40

Concentration of NaOH in g/L = number of moles/L × rel. mol mass
= 0.46 × 40
= 18.4 g / L

Answers (a) 0.46 moles/L
(b) 18.4 g/L

13.12

Balanced equation:

$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2H_2O$

Given:-

$V_a = \frac{16.7 + 16.8}{2} = 16.75\ cm^3$

$M_a = 0.15\ M$

$n_a = 1$

$V_b = 25\ cm^3$

$M_b = ?$

$n_b = 2$

$$\underset{H_2SO_4}{\frac{V_a \times M_a}{n_a}} = \underset{NaOH}{\frac{V_b \times M_b}{n_b}}$$

$$\frac{16.75 \times 0.15}{1} = \frac{25 \times M_b}{2}$$

$$\Rightarrow M_b = \frac{16.75 \times 0.15 \times 2}{25}$$

$$= 0.201\ \text{moles / L}$$

(Rel. mol mass NaOH = 23 + 16 + 1 = 40)

= 0.201 × 40 g/L
= 8.04 g / L

8.04 g NaOH / L = (8.04 / 4) g NaOH / 250 cm^3
= 2.01 g NaOH / 250 cm^3

$$\% \text{ purity of sample} = \frac{2.01}{2.5} \times 100 = 80.4\%$$

<u>13.13</u>

(a) Balanced equation:

$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$

Given:-

$V_a = 15.8\ cm^3$
$M_a = ?$
$n_a = 1$
$V_b = 25\ cm^3$
$M_b = 0.11$ M
$n_b = 1$

CH_3COOH		NaOH
$\frac{V_a \times M_a}{n_a}$	=	$\frac{V_b \times M_b}{n_b}$
$\frac{15.8 \times M_a}{1}$	=	$\frac{25 \times 0.11}{1}$

$$\Rightarrow M_a = \frac{25 \times 0.11}{15.8}$$

= 0.174 moles / L

⇒ Concentration of original solution = 0.174×5 (5 times more concentrated)
= 0.87 moles/L ……………….(a)
= 0.87×60
= 52.2 g/L ………………(b)

M_r CH_3COOH = 12 + 3(1) +12 + 2(16) + 1 = 12 + 3 +12 + 32 + 1 = 60

Concentration of CH_3COOH in w/v = 5.22 g/100 cm^3 = 5.22% w/v ……(c)

Answers:
(a) 0.87 moles/L
(b) 52.2 g/L
(c) 5.22% w/v

13.14

(a)

Balanced equation:

$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$

Given:

$V_a = 26.55\ cm^3$

$M_a = ?$

$n_a = 1$

$V_b = 25\ cm^3$

$M_b = 0.09\ M$

$n_b = 1$

CH_3COOH		NaOH

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{26.55 \times M_a}{1} = \frac{25 \times 0.09}{1}$$

$$\Rightarrow M_a = \frac{25 \times 0.09}{26.55}$$

$$= 0.0847 \text{ moles/L}$$

$\Rightarrow$ Concentration of original solution $= 0.0847 \times 10$ (10 times more concentrated)

$= 0.847$ moles / L ……….(a)

$= 0.847 \times 60$

$= 50.82$ g/L ……………(b)

M_r $CH_3COOH = 12 + 3(1) + 12 + 2(16) + 1 = 12 + 3 + 12 + 32 + 1 = 60$

Concentration of CH_3COOH in w/v = 5.08 g/100 cm^3 = 5.08% w/v …..(c)

Answers:
(a) 0.847 moles/L
(b) 50.82 g/L
(c) 5.08% w/v

13.15

(a) Balanced equation:

$Na_2CO_3 + 2HCl \longrightarrow 2NaCl + H_2O + CO_2$

Given:
$V_a = 29.38\ cm^3$
$M_a = 0.17\ M$
$n_a = 2$
$V_b = 25\ cm^3$
$M_b = ?$
$n_b = 1$

HCl | Na_2CO_3

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{29.38 \times 0.17}{2} = \frac{25 \times M_b}{1}$$

$$\Rightarrow M_b = \frac{29.38 \times 0.17}{25 \times 2}$$

$$= 0.0999 \text{ moles/L}$$

0.0999 moles $Na_2CO_3\ xH_2O$/L = (0.0999 / 4) moles $Na_2CO_3\ xH_2O$ / 250cm^3
= 0.025 moles $Na_2CO_3\ xH_2O$ / 250 cm^3

1 mole Na_2CO_3 = 2(23) + 12 +3(16)
= 46 + 12 + 48 = 106 g

$\Rightarrow$ 0.025 moles Na_2CO_3 = 0.025 × 106 = 2.65 g

$\Rightarrow$ Mass of water of crystallisation = 7.16 - 2.65
= 4.51 g

$$\% \text{ Water of crystallisation} = \frac{4.51}{7.16} \times 100 = 62.99\%$$

(b) Next, calculate the value of x in the formula $Na_2CO_3\ xH_2O$. Note from above that by dissolving 7.16 g of the crystals of $Na_2CO_3\ xH_2O$ in 250 cm^3 of solution, we obtain a solution which contains 0.025 moles.

Therefore, 0.025 moles $Na_2CO_3\ xH_2O$ = 7.16 g

$$1 \text{ mole } Na_2CO_3\ xH_2O = \frac{7.16}{0.025} = 286.4$$

i.e. Rel. mol mass of $Na_2CO_3\ xH_2O$ = 286.4
$\Rightarrow$ 2(23) + 12 + 3(16) + x(2 +16) = 286.4
106 + 18x = 286.4
solve for x
18x =180.4
x = 10.02 ≈ 10
i.e. formula is Na_2CO_3 **10**H_2O

Answers:
(a) % Water of crystallisation = 62.99%
(b) x =10

13.16

(a) Balanced equation:

$Na_2CO_3 + 2HCl \longrightarrow 2NaCl + H_2O + CO_2$

Given:

$V_a = 22.8\ cm^3$

$M_a = 0.11\ M$

$n_a = 2$

$V_b = 25\ cm^3$

$M_b = ?$

$n_b = 1$

HCl Na_2CO_3

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{22.8 \times 0.11}{2} = \frac{25 \times M_b}{1}$$

$$\Rightarrow M_b = \frac{22.8 \times 0.11}{25 \times 2}$$

$$= 0.0502 \text{ moles/L}$$

0.0502 moles $Na_2CO_3\ xH_2O$/L = (0.0502 / 2) moles $Na_2CO_3\ xH_2O$ / 500 cm^3
= 0.0251 moles $Na_2CO_3\ xH_2O$ / 500 cm^3

1 mole Na_2CO_3 = 2(23) + 12 +3(16)
= 46 + 12 + 48 = 106 g

$\Rightarrow$ 0.0251 moles Na_2CO_3 = $0.0251 \times 106 = 2.66$ g

$\Rightarrow$ Mass of water of crystallisation = 3.55 - 2.66
= 0.89 g

$$\% \text{ Water of crystallisation} = \frac{0.89}{3.55} \times 100 = 25.07\%$$

(b) Next, calculate the value of x in the formula $Na_2CO_3\ xH_2O$ .Note from above that by dissolving 3.55 g of the crystals of $Na_2CO_3\ xH_2O$ in 500 cm^3 of solution, we obtain a solution which contains 0.0251 moles.

Therefore, 0.0251 moles $Na_2CO_3\ xH_2O$ = 3.55 g

$$1 \text{ mole } Na_2CO_3\ xH_2O = \frac{3.55}{0.0251} = 141.43$$

i.e. Rel. mol mass of $Na_2CO_3\ xH_2O$ = 141.43

$\Rightarrow 2(23) + 12 + 3(16) + x(2 + 16) = 141.43$

$106 + 18x = 141.43$

solve for x $18x = 35.43$

$x = 1.97 \approx 2$

i.e. formula is $Na_2CO_3.2H_2O$

Answers: (a) % Water of crystallisation = 25.07%

(b) x = 2

Chapter 15 Volumetric Analysis: Oxidation-Reduction

15.1

(a) Balanced equation:

$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:

$V_o = 22.85\ cm^3$
$M_o = ?$
$n_o = 1$
$V_r = 25\ cm^3$
$M_{red} = 0.15\ M$
$n_r = 5$

MnO_4^- Fe^{2+}

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{22.85 \times M_o}{1} = \frac{25 \times 0.15}{5}$$

$$\Rightarrow M_o = \frac{25 \times 0.15}{5 \times 22.85}$$

$= 0.0328$ moles/L
$= 0.0328 \times 158$ (M_r $KMnO_4 = 158$)
$= 5.18$ g / L

Answer: (a) 0.0328 moles/L (b) 5.18 g / L

15.2

(a) Balanced equation:

$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:

$V_o = 23.45\ cm^3$
$M_o = 0.02\ M$
$n_o = 1$
$V_r = 25\ cm^3$
$M_{red} = ?$
$n_r = 5$

MnO_4^- Fe^{2+}

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{23.45 \times 0.02}{1} = \frac{25 \times M_{red}}{5}$$

$$\Rightarrow M_{red} = \frac{23.45 \times 0.02 \times 5}{25}$$

$= 0.0938$ moles/L
$= 0.0938 \times 278$ (M_r $FeSO_4.7H_2O = 278$)
$= 26.08$ g/L

Answer: (a) 0.0938 moles/L (b) 26.08 g/L

15.3
First calculate concentration of ammonium iron(II) sulfate solution.

392 g of $(NH_4)_2(SO_4)FeSO_4.6H_2O$ in 1 L of solution $\longrightarrow$ 1 M solution

1 g of $(NH_4)_2(SO_4)FeSO_4.6H_2O$ in 1 L of solution $\longrightarrow \frac{1}{392}$ M solution

10.52 g of $(NH_4)_2(SO_4)FeSO_4.6H_2O$ in 1 L of solution $\longrightarrow \frac{1 \times 10.52}{392}$ M solution

10.52 g of $(NH_4)_2(SO_4)FeSO_4.6H_2O$ in 250 cm^3 of solution $\longrightarrow \frac{4 \times 10.52}{392}$ M solution

$= 0.1073$ M

Balanced equation:
$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:-
$V_o = 23.8\ cm^3$
$M_o = ?$
$n_o = 1$
$V_r = 25\ cm^3$
$M_{red} = 0.1073$ M
$n_r = 5$

MnO_4^- $\quad$ Fe^{2+}

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{23.8 \times M_o}{1} = \frac{25 \times 0.1073}{5}$$

$$\Rightarrow M_o = \frac{25 \times 0.1073}{5 \times 23.8}$$

$= 0.0225$ moles/L (M_r $KMnO_4$ = 158)

$= 0.0225 \times 158$
$= 3.56$ g / L

Answer: (a) 0.0225 moles/L (b) 3.56 g/L

15.4

(d) Balanced equation:

$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:

$V_o = 21.8\ cm^3$

$M_o = 0.02\ M$

$n_o = 1$

$V_r = 25\ cm^3$

$M_{red} = ?$

$n_r = 5$

$$\begin{array}{ccc} MnO_4^- & & Fe^{2+} \end{array}$$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{21.8 \times 0.02}{1} = \frac{25 \times M_{red}}{5}$$

$$\Rightarrow M_{red} = \frac{21.8 \times 0.02 \times 5}{25}$$

$$= 0.0872 \text{ moles/L}$$

0.0872 moles $FeSO_4.xH_2O$ / L = (0.0872 / 4) moles $FeSO_4.xH_2O$ / 250 cm^3
= 0.0218 moles $FeSO_4.xH_2O$ / 250 cm^3

i.e. by dissolving 6.08 g of the crystals of $FeSO_4.xH_2O$ in 250 cm^3 of solution, we obtain a solution which contains 0.0218 moles.

Therefore, 0.0218 moles $FeSO_4.xH_2O$ = 6.08 g

$$1 \text{ mole } FeSO_4.xH_2O = \frac{6.08}{0.0218} = 278.90$$

$$\Rightarrow 56 + 32 + 4(16) + x(2 + 16) = 278.90$$

$$152 + 18x = 278.90$$

$$18x = 126.9$$

$$x = 7.05 \approx 7$$

i.e. formula is $FeSO_4.\mathbf{7}H_2O$

Answer: x = 7

<u>15.5</u>

Balanced equation:

$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:

$V_o = 23.85\ cm^3$

$M_o = 0.021\ M$

$n_o = 1$

$V_{red} = 25\ cm^3$

$M_{red} = ?$

$n_r = 5$

$$\begin{array}{ccc} MnO_4^- & & Fe^{2+} \\ \dfrac{V_o \times M_o}{n_o} & = & \dfrac{V_r \times M_{red}}{n_r} \\ \dfrac{23.85 \times 0.021}{1} & = & \dfrac{25 \times M_{red}}{5} \end{array}$$

$$\Rightarrow M_{red} = \frac{23.85 \times 0.021 \times 5}{25}$$

$$= 0.1002 \text{ moles/L}$$

0.1002 moles $(NH_4)_2\ SO_4FeSO_4.xH_2O$ / L = (0.1002 / 4) moles $(NH_4)_2\ SO_4FeSO_4.xH_2O$ / 250 cm^3

= 0.0251 moles $(NH_4)_2\ SO_4FeSO_4.xH_2O$ / 250 cm^3

i.e. by dissolving 9.8 g of the crystals of $(NH_4)_2\ SO_4FeSO_4.xH_2O$ in 250 cm^3 of solution, we obtain a solution which contains 0.0251 moles.

Therefore, 0.0251 moles $(NH_4)_2\ SO_4FeSO_4.xH_2O$ = 9.8 g

$$1 \text{ mole } (NH_4)_2\ SO_4FeSO_4.xH_2O = \frac{9.8}{0.0251} = 390.44$$

$$\Rightarrow 2(14) + 8(1) + 32 + 4(16) + 56 + 32 + 4(16) + x(2 + 16) = 390.44$$

$$284 + 18x = 390.44$$

$$18x = 106.44$$

$$x = 5.91 \approx 6$$

i.e. formula is $(NH_4)_2\ SO_4FeSO_4.6H_2O$

15.6

(ii) Balanced equation:

$5Fe^{2+} + MnO_4^- + 8H^+ \longrightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

Given:-

$V_o = 20\ cm^3$

$M_o = 0.02\ M$

$n_o = 1$

$V_r = 25\ cm^3$

$M_{red} = ?$

$n_r = 5$

$$MnO_4^- \qquad Fe^{2+}$$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{20 \times 0.02}{1} = \frac{25 \times M_{red}}{5}$$

$$\Rightarrow M_r = \frac{20 \times 0.02 \times 5}{25}$$

$= 0.08$ moles/L

(iii)

0.08 moles $FeSO_4(NH_4)_2\ SO_4.xH_2O$/L = (0.08 / 4) moles $FeSO_4(NH_4)_2\ SO_4.xH_2O/250cm^3$

= 0.02 moles $FeSO_4(NH_4)_2\ SO_4.xH_2O$ / 250 cm^3

i.e. by dissolving 7.84 g of the crystals of $(NH_4)_2\ SO_4FeSO_4.xH_2O$ in 250 cm^3 of solution, we obtain a solution which contains 0.02 moles.

Therefore, 0.02 moles $(NH_4)_2\ SO_4FeSO_4.xH_2O$ = 7.84 g

$$1 \text{ mole } (NH_4)_2\ SO_4FeSO_4.xH_2O = \frac{7.84}{0.02} = 392$$

$\Rightarrow 56 + 32 + 4(16) + 2(14) + 8(1) + 32 + 4(16) + x(2 + 16) = 392$

$284 + 18x = 392$

$18x = 108$

$x = 6$

i.e. formula is $FeSO_4(NH_4)_2\ SO_4.6H_2O$

Answers : (ii) 0.08 moles/L (iii) x = 6

15.7

(iii)

(a) Balanced equation:

$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:-

$V_o = 9.15\ cm^3$

$M_o = 0.01\ M$

$n_o = 1$

$V_r = 20\ cm^3$

$M_{red} = ?$

$n_r = 5$

MnO_4^-		Fe^{2+}

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{9.15 \times 0.01}{1} = \frac{20 \times M_{red}}{5}$$

$$\Rightarrow M_{red} = \frac{9.15 \times 0.01 \times 5}{20}$$

$$= 0.0229\ moles / L$$
$$= 0.0229 \times 152$$
$$= 3.48\ g / L$$

(Rel. mol mass $FeSO_4$ = 56 + 32 + 4(16) = 152)

Therefore, in the 250 cm^3 volumetric flask there are 3.48 / 4 g = 0.87 g $FeSO_4$

i.e. 5 tablets contain 0.87 g $FeSO_4$

$\Rightarrow$ 1 tablet contains (0.87 / 5) g = 0.174 g $FeSO_4$

(b)

$$\%\ of\ Fe\ in\ FeSO_4 = \frac{\text{Rel. atomic mass Fe}}{\text{Rel. mol. mass } FeSO_4} \times 100$$

$$= \frac{56}{152} \times 100 = 36.84\%$$

$\Rightarrow$ Mass of Fe in each tablet = 36. 84% of 0.174 g

$$= \frac{36.84}{100} \times 0.174 = 0.064\ g$$

(c)

$$\text{Mass of 1 tablet} = \frac{1.69}{5} = 0.338\ g$$

$$\%\ FeSO_4 \text{ in each tablet} = \frac{\text{Mass of } FeSO_4 \text{ in tablet}}{\text{Mass of 1 tablet}} \times 100$$

$$= \frac{0.174}{0.338} \times 100 = 51.48\ \%$$

Answer: (iii) (a) 0.174 g (b) 0.064 g (c) 51.48%

15.8

(iv)

(a) Balanced equation :-

$MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Given:-

$V_o = 4.51\ cm^3$

$M_o = 0.015\ M$

$n_o = 1$

$V_r = 25\ cm^3$

$M_{red} = ?$

$n_r = 5$

$$\begin{array}{cc} MnO_4^- & Fe^{2+} \end{array}$$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{4.51 \times 0.015}{1} = \frac{25 \times M_{red}}{5}$$

$$\Rightarrow M_{red} = \frac{4.51 \times 0.015 \times 5}{25}$$

$$= 0.0135\ moles / L$$
$$= 0.0135 \times 152$$
$$= 2.05\ g / L$$

(Rel. molecular mass $FeSO_4$ = 56 + 32 + 4(16) = 152)

Therefore, in the 250 cm^3 volumetric flask there are 2.05 / 4 g = 0.513 g $FeSO_4$

i.e. 4 tablets contain 0.513 g $FeSO_4$

$\Rightarrow$ 1 tablet contains (0.513 / 4) g = 0.128 g $FeSO_4$

(b)

$$\%\ \text{of Fe in } FeSO_4 = \frac{\text{Rel. atomic mass Fe}}{\text{Rel. mol. mass } FeSO_4} \times 100$$

$$= \frac{56}{152} \times 100 = 36.84\ \%$$

$\Rightarrow$ Mass of Fe in each tablet = 36. 84 % of 0.128 g

$$= \frac{36.84}{100} \times 0.128 = 0.047\ g$$

(c)

$$\text{Mass of 1 tablet} = \frac{0.96}{4} = 0.24 \text{ g}$$

$$\% \ FeSO_4 \text{ in each tablet} = \frac{\text{Mass of } FeSO_4 \text{ in tablet}}{\text{Mass of 1 tablet}} \times 100$$

$$= \frac{0.128}{0.24} \times 100 = 53.33\%$$

Answer: (iv) (a) 0.128 g (b) 0.047 g (c) 53.33%

15.9

(a) Balanced equation:

$$2S_2O_3^{2-} + I_2 + \longrightarrow S_4O_6^{2-} + 2I^-$$

Given:-

$V_o = 25 \text{ cm}^3$

$M_o = 0.05$ M

$n_o = 1$

$V_r = 18.55 \text{ cm}^3$

$M_{red} = ?$

$n_r = 2$

I_2		$S_2O_3^{2-}$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{25 \times 0.05}{1} = \frac{18.55 \times M_{red}}{2}$$

$$\Rightarrow M_{red} = \frac{25 \times 0.05 \times 2}{18.55}$$

$= 0.1348$ moles/L

$= 0.1348 \times 248$

$= 33.43$ g/L

(Rel molecular mass $Na_2S_2O_3.5H_2O$ = 248)

Answer: (a) 0.1348 moles/L, (b) 33.43 g/L

15.10

(v) (a)

$2MnO_4^- + 10I^- + 16H^+ \longrightarrow 2Mn^{2+} + 5I_2 + 8H_2O$

$I_2 + 2S_2O_3^{2-} \longrightarrow S_4O_6^{2-} + 2I^-$

From the balanced equations, we see that 2 moles of MnO_4^- produce five moles of I_2 and these 5 moles of I_2 would then react with 10 moles of $S_2O_3^{2-}$.

i.e. $\mathbf{\underline{2}MnO_4^-} = 5I_2 = \mathbf{\underline{10}S_2O_3^{2-}}$

Given:

$V_o = 25\ cm^3$

$M_o = 0.018\ M$

$n_o = 2$

$V_r = 15.6\ cm^3$

$M_{red} = ?$

$n_r = 10$

$$\frac{V_o \times M_o}{n_o}\ (MnO_4^-) = \frac{V_r \times M_{red}}{n_r}\ (S_2O_3^{2-})$$

$$\frac{25 \times 0.018}{2} = \frac{15.6 \times M_{red}}{10}$$

$$\Rightarrow M_{red} = \frac{25 \times 0.018 \times 10}{2 \times 15.6}$$

$= 0.1442$ moles/L

$= 0.1442 \times 248$

$= 35.76$ g/L

(Rel molecular mass $Na_2S_2O_3.5H_2O = 248$)

Answer: (a) 0.1442 moles/L, (b) 35.76 g/L

<u>15.11</u>

(vii) (a)

$ClO^- + 2I^- + 2H^+ \longrightarrow Cl^- + I_2 + H_2O$

$2S_2O_3^{2-} + I_2 \longrightarrow S_4O_6^{2-} + 2I^-$

From the balanced equations, we see that 1 mole of ClO^- produce 1 moles of I_2 and this 1 mole of I_2 would then react with 2 moles of $S_2O_3^{2-}$.

i.e. **<u>1</u>ClO^- =** $1I_2$ **= <u>2</u>$S_2O_3^{2-}$**

Given:

$V_o = 25\ cm^3$

$M_o = ?$

$n_o = 1$

$V_r = 22.4\ cm^3$

$M_{red} = 0.22\ M$

$n_r = 2$

$$\begin{array}{ccc} ClO^- & & S_2O_3^{2-} \\ \dfrac{V_o \times M_o}{n_o} & = & \dfrac{V_r \times M_{red}}{n_r} \\ \dfrac{25 \times M_o}{1} & = & \dfrac{22.4 \times 0.22}{2} \end{array}$$

$$\Rightarrow M_o = \frac{22.4 \times 0.22}{2 \times 25}$$

$$= 0.0986 \text{ moles / L}$$

$$\Rightarrow \text{Concentration of original solution} = 0.0986 \times 10 \quad \text{(10 times more concentrated)}$$

$$= 0.986\ M$$

$$= 0.986 \times 74.5$$

$$= 73.46\ g/L$$

$$= 7.346\ g/100\ cm^3$$

$$= 7.35\ \%\ w/v$$

Answer: (a) 0.986 moles/L, (b) 73.46 g/L, (c) 7.35% w/v.

(c) Concentration of NaClO in w/v

15.12

(v) (a)

$ClO^- + 2I^- + 2H^+ \longrightarrow Cl^- + I_2 + H_2O$

$2S_2O_3^{2-} + I_2 \longrightarrow S_4O_6^{2-} + 2I^-$

From the balanced equations, we see that 1 mole of ClO^- produce 1 moles of I_2 and this 1 mole of I_2 would then react with 2 moles of $S_2O_3^{2-}$.

i.e. $\mathbf{\underline{1}ClO^-} = 1I_2 = \mathbf{\underline{2}S_2O_3^{2-}}$

Given:

$V_o = 25\ cm^3$

$M_o = ?$

$n_o = 1$

$V_r = \frac{24.9 + 25}{2} = 24.95\ cm^3$

$M_{red} = 0.1\ M$

$n_r = 2$

	ClO^-		$S_2O_3^{2-}$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{red}}{n_r}$$

$$\frac{25 \times M_o}{1} = \frac{24.95 \times 0.1}{2}$$

$$\Rightarrow M_o = \frac{24.95 \times 0.1}{2 \times 25}$$

$= 0.0499$ moles/L

Concentration of original solution $= 0.0499 \times 10$ moles/L

$= 0.499$ moles/L

$= 0.499 \times 74.5$ g/L (M_r NaClO = 74.5)

$= 37.18$ g/L

$= 3.718\ g/100\ cm^3$

$= 3.72$ % w / v

Answer: (a) 0.499 moles/L, (b) 37.18 g/L, (c) 3.72%

Chapter 16 – Rates of Reaction

16.3

(i) graph

(ii) 210 seconds - the reaction is complete at a time of 210 seconds as after this time, the volume of O_2 evolved remains constant at 200 cm^3.

(iii) Fraction of H_2O_2 decomposed in first minute $= \frac{150}{200} = \frac{3}{4}$

16.5

(ii)

$$\text{number of moles of } H_2SO_4 = \frac{V \times M}{1000}$$

$$= \frac{25 \times 0.1}{1000} = 2.5 \times 10^{-3}$$

$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$

$H_2SO_4 \longrightarrow H_2$ (shortened version of equation)

1 mole $\longrightarrow$ 1 mole

1 mole $\longrightarrow$ 22.4 L at s.t.p.

i.e. 2.5×10^{-3} mole $H_2SO_4 \longrightarrow (2.5 \times 10^{-3} \times 22.4)$ L of H_2 at s.t.p.

$= 0.056$ L of H_2

$= 56\ cm^3$

(iv) graph

(iv) Some sample results from the graph:

$$\text{Instantaneous rate of reaction at 2 minutes} = \frac{54.5 - 35.5}{3 - 1} = \frac{19}{2} = 9.5\ cm^3\text{ / minute}$$

Any value between 9.5 – 11 cm^3/min is acceptable.

Chapter 17 – Chemical Equilibrium

17.6

	CH_3COOH	+ C_2H_5OH	⇌	$CH_3COOC_2H_5$	+ H_2O
Initially:	1	1		0	0
At Equil.	0.33	0.33		0.67	0.67
Conc. at equil.	[0.33 / V]	[0.33 / V]		[0.67 / V]	[0.67 / V]

V is the volume of the container which we are not given in the question.

$$K_c = \frac{[CH_3COOC_2H_5]\,[H_2O]}{[CH_3COOH]\,[C_2H_5OH]} = \frac{(0.67 / V)\,(0.67 / V)}{(0.33 / V)\,(0.33 / V)}$$

The V terms cancel out in the Kc expression

$$\therefore \quad K_c = \frac{(0.67)\,(0.67)}{(0.33)\,(0.33)} = 4.12$$

Answer: $K_c = 4.12$

17.7

	$2HI$	⇌	H_2	+	I_2
Initially	1		0		0
At Equil.	1 – 0.2 = 0.8		0.1		0.1
Conc. at equil. (V = 1 L)	[0.8]		[0.1]		[0.1]

$$K_c = \frac{[H_2]\,[I_2]}{[HI]}$$

$$\Rightarrow \quad K_c = \frac{(0.1)\,(0.1)}{(0.8)^2} = 0.0156$$

Answer: $K_c = 0.0156$

<u>17.8</u>

(ii)	$2BrCl \rightleftharpoons$	Br_2 +	Cl_2
Initially	0.9	0	0
At Equil.	0.9 – 0.8 = 0.1	0.4	0.4
Conc. at equil. (V = 5 L)	$\frac{0.1}{5}$ = [0.02]	$\frac{0.4}{5}$ = [0.08]	$\frac{0.4}{5}$ = [0.08]

$$K_c = \frac{[Br_2]\,[Cl_2]}{[BrCl]^2}$$

$$\Rightarrow K_c = \frac{(0.08)\,(0.08)}{(0.02)^2} = 16$$

(iv) $BrCl \rightleftharpoons \frac{1}{2}Br_2 + \frac{1}{2}Cl_2$

$$K'_c = \frac{[Br_2]^{1/2}\,[Cl_2]^{1/2}}{[BrCl]} = \sqrt{K_c}$$

$$\Rightarrow K'_c = \sqrt{16} = 4$$

Answer: (ii) $K_c = 16$
(iv) $K'_c = 4$

Chapter 18 – pH and Indicators

18.2

(a) pH = - $\log_{10}[H^+]$ = - $\log_{10}(10^{-7})$
= 7

(b) pH = - $\log_{10}[H^+]$ = - $\log_{10}(4 \times 10^{-3})$
= 2.40

(c) pH = - $\log_{10}[H^+]$ = - $\log_{10}(2.62 \times 10^{-8})$
= 7.58

(d) pH = - $\log_{10}[H^+]$ = - $\log_{10}(5.2 \times 10^{-3})$
= 2.28

(e) pH = - $\log_{10}[H^+]$ = - $\log_{10}(8.7 \times 10^{-11})$
= 10.06

18.3

(a) pH = - $\log_{10}[H^+]$ = 5.65
$\log_{10}[H^+]$ = - 5.65
$\Rightarrow$ $[H^+]$ = antilog (- 5.65)
= 2.24×10^{-6} mol/L

(b) pH = - $\log_{10}[H^+]$ = 11.15
$\log_{10}[H^+]$ = - 11.15
$\Rightarrow$ $[H^+]$ = antilog (- 11.15)
= 7.08×10^{-12} mol/L

(c) pH = - $\log_{10}[H^+]$ = 1.09
$\log_{10}[H^+]$ = - 1.09
$\Rightarrow$ $[H^+]$ = antilog (- 1.09)
= 0.08 mol/L

(d) pH = - $\log_{10}[H^+]$ = 7
$\log_{10}[H^+]$ = - 7
$\Rightarrow$ $[H^+]$ = antilog (- 7)
= 1×10^{-7} mol/L

(e) pH = - $\log_{10}[H^+]$ = 9.65
$\log_{10}[H^+]$ = - 9.65
$\Rightarrow$ $[H^+]$ = antilog (- 9.65)
= 2.24×10^{-10} mol/L

18.4

(a) $HCl \longrightarrow H^+ + Cl^-$
1 mole $\longrightarrow$ 1 mole
$\Rightarrow$ 0.1 mole $\longrightarrow$ 0.1 mole

pH = - $\log_{10}[H^+]$ = $-\log_{10}(0.1)$ = 1

(b) $H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$

1 mole $\longrightarrow$ 2 mole

$\Rightarrow$ 0.01 mole $\longrightarrow$ 0.01 $\times$ 2 mole

= 0.02 mole

$pH = -\log_{10}[H^+] = -\log_{10}(0.02) = 1.70$

(c) 12.6 g HNO_3 / 500 cm^3 = (12.6 $\times$ 2) g HNO_3 / L = 25.2 g HNO_3 / L

Rel molecular mass HNO_3 = 1 + 14 + 3(16) = 63

$$\text{Number of moles of } HNO_3/\text{ L} = \frac{\text{Mass in 1L}}{\text{Rel molecular mass}} = \frac{25.2}{63} = 0.4$$

$HNO_3 \longrightarrow H^+ + NO_3^-$

1 mole $\longrightarrow$ 1 mole

$\Rightarrow$ 0.4 mole $\longrightarrow$ 0.4 mole

$pH = -\log_{10}[H^+] = -\log_{10}(0.4) = 0.40$

(d) 5.48 g HCl / 500 cm^3 = (5.48 $\times$ 2) g HCl / L = 10.96 g HCl / L

Rel molecular mass HCl = 1 + 35.5 = 36.5

$$\text{Number of moles of HCl / L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{10.96}{36.5} = 0.3$$

$HCl \longrightarrow H^+ + Cl^-$

1 mole $\longrightarrow$ 1 mole

$\Rightarrow$ 0.3 mole $\longrightarrow$ 0.3 mole

$pH = -\log_{10}[H^+] = -\log_{10}(0.3) = 0.52$

(e) 5.8 g H_2SO_4 / 250 cm^3 = (5.8 $\times$ 4) g H_2SO_4 / L = 23.2 g H_2SO_4 / L

Rel molecular mass H_2SO_4 = 2(1) + 32 + 4(16) = 98

$$\text{Number of moles of } H_2SO_4 \text{ / L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{23.2}{98} = 0.24$$

$H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$

1 mole $\longrightarrow$ 2 mole

$\Rightarrow$ 0.24 mole $\longrightarrow$ 0.24 $\times$ 2 mole

= 0.48 mole

$pH = -\log_{10}[H^+] = -\log_{10}(0.48) = 0.32$

18.5

(a) $NaOH \longrightarrow Na^{+} + OH^{-}$

1 mole ⟶ 1 mole

⇒ 0.95 mole ⟶ 0.95 mole

$pOH = -\log_{10}[OH^{-}] = -\log_{10}(0.95) = 0.02$

$pH = 14 - pOH = 14 - 0.02 = 13.98$

(b) $NaOH \longrightarrow Na^{+} + OH^{-}$

1 mole ⟶ 1 mole

⇒ 5 moles ⟶ 5 moles

$pOH = -\log_{10}[OH^{-}] = -\log_{10}(5) = -0.70$

$pH = 14 - pOH = 14 - (-0.70) = 14.70$

(c) 1 g NaOH / 500 cm^3 = (1×2) g NaOH / L = 2 g NaOH / L

Rel molecular mass NaOH = 23 + 16 + 1 = 40

$$\text{Number of moles of NaOH / L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{2}{40} = 0.05$$

$NaOH \longrightarrow Na^{+} + OH^{-}$

1 mole ⟶ 1 mole

⇒ 0.05 mole ⟶ 0.05 mole

$pOH = -\log_{10}[OH^{-}] = -\log_{10}(0.05) = 1.30$

$pH = 14 - pOH = 14 - 1.30 = 12.70$

(d) 0.024 g KOH / L

Rel molecular mass KOH = 39 + 16 + 1 = 56

$$\text{Number of moles of KOH / L} = \frac{\text{Mass in 1L}}{\text{Rel molecular mass}} = \frac{0.024}{56} = 4.3 \times 10^{-4}$$

$KOH \longrightarrow K^{+} + OH^{-}$

1 mole ⟶ 1 mole

⇒ 4.3×10^{-4} mole ⟶ 4.3×10^{-4} mole

$pOH = -\log_{10}[OH^{-}] = -\log_{10}(4.3 \times 10^{-4}) = 3.37$

$pH = 14 - pOH = 14 - 3.37 = 10.63$

(e) 0.37 g $Ca(OH)_2$ / 500 cm^3 = (0.37 × 2) g $Ca(OH)_2$/ L = 0.74 g $Ca(OH)_2$ / L

Rel molecular mass $Ca(OH)_2$ = 40 + 2(16) + 2(1) = 74

$$\text{Number of moles of } Ca(OH)_2 \text{ / L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{0.74}{74} = 0.01$$

$Ca(OH)_2 \longrightarrow Ca^{2+} + 2OH^-$

1 mole ⟶ 2 mole

⇒ 0.01 mole ⟶ 0.01 × 2 mole

= 0.02 mole

pOH = $-\log_{10}[OH^-] = -\log_{10}(0.02) = 1.70$

pH = 14 – pOH =14 – 1.70 = 12.30

<u>18.6</u>

(ii) 0.3 g CH_3COOH / 50 cm^3 = (0.3 × 20) g CH_3COOH / L = 6 g CH_3COOH / L

Rel molecular mass CH_3COOH = 12 + 3(1) + 12 + 2(16) + 1 = 60

$$\text{Number of moles of } CH_3COOH \text{ / L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{6}{60} = 0.1$$

Hydrogen ion concentration can be found by substituting into the formula:-

$[H^+] = \sqrt{K_a \times M_{acid}}$

$= \sqrt{1.8 \times 10^{-5} \times 0.1}$

$= 1.8 \times 10^{-6}$ mol/L

pH = $-\log_{10}[H^+] = -\log_{10}(1.34 \times 10^{-3}) = 2.87$

Answer: pH = 2.87

<u>18.7</u>

5×10^{-2} mole HA / 100 cm^3 = (5×10^{-2} × 10) mole HA / L = 0.5 mole HA / L

$[H^+] = \sqrt{K_a \times M_{acid}}$

$= \sqrt{5.5 \times 10^{-5} \times 0.5}$

$= \sqrt{2.75 \times 10^{-5}}$

$= 5.24 \times 10^{-3}$ mol/L

pH = $-\log_{10}[H^+] = -\log_{10}(5.24 \times 10^{-3}) = 2.28$

Answer: pH = 2.28

18.8

Hydrogen ion concentration can be found by substituting into the formula:-

$[H^+] = \sqrt{K_a \times M_{acid}}$

$= \sqrt{1.8 \times 10^{-5} \times 0.1}$

$= \sqrt{1.8 \times 10^{-6}}$

$= 1.34 \times 10^{-3}$ mol/L

Answer: 1.34×10^{-3} mol/L

18.9

$pH = -\log_{10}[H^+] = 2.37$

$\log_{10}[H^+] = -2.37$

$\Rightarrow [H^+] = \text{antilog}(-2.37)$

$= 4.27 \times 10^{-3}$ mol/L

K_a can be found by substituting into the formula:-

$[H^+] = \sqrt{K_a \times M_{acid}}$

Square both sides

$[H^+]^2 = K_a \times M_{acid}$

$(4.27 \times 10^{-3})^2 = K_a \times 1$

$\Rightarrow K_a = 1.8 \times 10^{-5}$

$[H^+] = \sqrt{K_a \times M_{acid}}$

$= \sqrt{1.8 \times 10^{-5} \times 0.05}$

$= \sqrt{9 \times 10^{-7}}$

$= 9.49 \times 10^{-4}$ mol/L

$pH = -\log_{10}[H^+] = -\log_{10}(9.49 \times 10^{-4}) = 3.02$

Answer: $[H^+] = 4.27 \times 10^{-3}$ mol/L

$pH = 3.02$

18.10

1M methanoic acid is 1.3% dissociated i.e. 1.3% of 1 mole

$$= \frac{1.3}{100} \times 1 = 0.013 \text{ mole of } H^+ \text{ ions are formed}$$

K_a can be found by substituting into the formula:

$[H^+] = \sqrt{K_a \times M_{acid}}$

Square both sides

$[H^+]^2 = K_a \times [acid]$

$(0.013)^2 = K_a \times 1$

$\Rightarrow \quad K_a = 1.69 \times 10^{-4}$

$= 1.7 \times 10^{-4}$

$pH = -\log_{10}[H^+] = -\log_{10}(0.013) = 1.89$

Answer: pH = 1.89

18.11

$1.5 \text{ g } C_2H_5NH_2 / 250 \text{ cm}^3 = (1.5 \times 4) \text{ g } C_2H_5NH_2 / L = 6 \text{ g } C_2H_5NH_2 / L$

Rel molecular mass $C_2H_5NH_2 = 2(12) + 5(1) + 14 + 2(1) = 45$

$$\text{Number of moles of } C_2H_5NH_2 / L = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{6}{45} = 0.133$$

Hydroxide ion concentration can be found by substituting into the formula:

$[OH^-] = \sqrt{K_b \times M_{base}}$

$= \sqrt{4.4 \times 10^{-4} \times 0.133}$

$= \sqrt{5.852 \times 10^{-5}}$

$= 7.65 \times 10^{-3}$ mol/L

$pOH = -\log_{10}[OH^-] = -\log_{10}(7.65 \times 10^{-3}) = 2.12$

$pH = 14 - pOH = 14 - 2.12 = 11.88$

Answer: pH = 11.88

18.13

(i) $C_2H_5COOH + NaOH \longrightarrow C_2H_5COONa + H_2O$

Ethanoic acid	Sodium Hydroxide
$V_a = 25\ cm^3$	$V_b = ?\ cm^3$
$M_a = 0.1\ M$	$M_b = 0.1\ M$
$n_a = 1$	$n_b = 1$

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{25 \times 0.1}{1} = \frac{V_b \times 0.1}{1}$$

$$V_b = \frac{25 \times 0.1}{0.1} = 25\ cm^3$$

Answer: 25 cm^3

18.17

(i) $HCOOH + NaOH \longrightarrow HCOONa + H_2O$

Methanoic acid	Sodium Hydroxide
$V_a = ?\ cm^3$	$V_b = 25\ cm^3$
$M_a = 0.1\ M$	$M_b = 0.108\ M$
$n_a = 1$	$n_b = 1$

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{V_a \times 0.1}{1} = \frac{25 \times 0.108}{1}$$

$$V_a = \frac{25 \times 0.108}{0.1} = 27\ cm^3$$

Answer: 27 cm^3

Chapter 19 – Environmental Chemistry – Water

Teachers may wonder why the sequence of steps involved in water treatment (pages 269 – 271 in textbook) is slightly different from that studied at Junior Certificate level in *The World of Science* (page 233). As a result of increased demand for water in recent years, modern water treatment plants do not have the capacity to store vast quantities of water. Therefore, flocculation is now carried out **before** settlement rather than first storing the water, allowing particles to settle and then carrying out flocculation.

<u>19.3</u>

Given:-
$V_{Ca} = 100\ cm^3$
$M_{Ca} = ?$
$n_{Ca} = 1$
$V_{ed} = 25\ cm^3$
$M_{ed} = 0.025\ M$
$n_{ed} = 1$

Ca^{2+} edta

$$\frac{V_{Ca} \times M_{Ca}}{n_{Ca}} = \frac{V_{ed} \times M_{ed}}{n_{ed}}$$

$$\frac{100 \times M_{Ca}}{1} = \frac{25 \times 0.025}{1}$$

$$\Rightarrow M_{Ca} = \frac{25 \times 0.025}{100}$$

$= 6.25 \times 10^{-3}$ moles/L $CaCO_3$
$= 6.25 \times 10^{-3} \times 100$ g/L $CaCO_3$ ($M_r CaCO_3 = 100$)
$= 0.625$ g/L $CaCO_3$
$= 0.625 \times 1{,}000$ mg/L $CaCO_3$
$= 625$ mg/L $CaCO_3$
$= 625$ p.p.m. $CaCO_3$

Answer: Total hardness of water = 625 p.p.m.

<u>19.4</u>
(vi) <u>Total hardness</u>
Given:-
$V_{Ca} = 100\ cm^3$
$M_{Ca} = ?$
$n_{Ca} = 1$
$V_{ed} = 19 cm^3$
$M_{ed} = 0.01\ M$
$n_{ed} = 1$

Ca^{2+} edta

$$\frac{V_{Ca} \times M_{Ca}}{n_{Ca}} = \frac{V_{ed} \times M_{ed}}{n_{ed}}$$

$$\frac{100 \times M_{Ca}}{1} = \frac{19 \times 0.01}{1}$$

$$\Rightarrow M_{Ca} = \frac{19 \times 0.01}{100}$$

$= 1.9 \times 10^{-3}$ moles/L $CaCO_3$
$= 1.9 \times 10^{-3} \times 100$ g/L $CaCO_3$ (M_r $CaCO_3$ =100)
= 0. 19 g/L $CaCO_3$
$= 0.19 \times 1000$ mg/L $CaCO_3$
= 190 mg/L $CaCO_3$
= 190 p.p.m. $CaCO_3$

Permanent hardness

Given:-
$V_{Ca} = 100\ cm^3$
$M_{Ca} = ?$
$n_{Ca} = 1$
$V_{ed} = 6\ cm^3$
$M_{ed} = 0.01$ M
$n_{ed} = 1$

Ca^{2+} edta

$$\frac{V_{Ca} \times M_{Ca}}{n_{Ca}} = \frac{V_{ed} \times M_{ed}}{n_{ed}}$$

$$\frac{100 \times M_{Ca}}{1} = \frac{6 \times 0.01}{1}$$

$$\Rightarrow M_{Ca} = \frac{6 \times 0.01}{100}$$

$= 6 \times 10^{-4}$ moles/L $CaCO_3$
$= 6 \times 10^{-4} \times 100$ g/L $CaCO_3$ (M_r $CaCO_3$ =100)
= 0. 06 g/L $CaCO_3$
$= 0.06 \times 1000$ mg/L $CaCO_3$
= 60 mg/L $CaCO_3$
= 60 p.p.m. $CaCO_3$

Hardness due to calcium hydrogen carbonate (temporary)
= Total hardness – Permanent hardness
= 190 – 60 = 130 p.p.m.

Answer: Total hardness of water = 190 p.p.m.
Hardness due to calcium hydrogen carbonate = 130 p.p.m.

19.6

Total suspended solids = 0.52 g / 250 cm^3
= 0.52×4 g/L
= $0.52 \times 4 \times 1{,}000$ mg/L
= 2080 p.p.m.

Total dissolved solids = 0.34 g / 100 cm^3
= 0.34×10 g/L
= $0.34 \times 10 \times 1{,}000$ mg/L
= 3400 p.p.m.

Answer: Total suspended solids = 2080 p.p.m.
Total dissolved solids = 3400 p.p.m.

19.7

Given:-

$V_o = 100\ cm^3$

$M_o = ?$

$n_o = 1$

$V_r = 8.8\ cm^3$

$M_r = 0.02\ M$

$n_r = 4$

$O_2 \qquad S_2O_3^{2-}$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_r}{n_r}$$

$$\frac{100 \times M_o}{1} = \frac{8.8 \times 0.02}{4}$$

$$\Rightarrow M_o = \frac{8.8 \times 0.02}{4 \times 100}$$

$= 4.4 \times 10^{-4}$ moles/L

$= 4.4 \times 10^{-4} \times 32$ g/L (Rel molecular mass $O_2 = 32$)

$= 0.01408$ g/L

$= 0.01408 \times 1000$ mg/L

$= 14.08$ mg/L

$= 14.08$ p.p.m.

Answer: Dissolved oxygen = 14.08 p.p.m.

19.9

Given:-

$V_o = 150\ cm^3$

$M_o = ?$

$n_o = 1$

$V_r = 21.7\ cm^3$

$M_r = 0.01\ M$

$n_r = 4$

$O_2 \qquad S_2O_3^{2-}$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_r}{n_r}$$

$$\frac{150 \times M_o}{1} = \frac{21.7 \times 0.01}{4}$$

$$\Rightarrow M_o = \frac{21.7 \times 0.01}{4 \times 150}$$

$= 3.62 \times 10^{-4}$ moles/L

$= 3.62 \times 10^{-4} \times 32$ g/L (Rel molecular mass $O_2 = 32$)

$= 0.01158$ g/L

$= 0.01158 \times 1000$ mg/L

$= 11.58$ mg/L

$= 11.58$ p.p.m.

Answer: Dissolved oxygen = 11.58 p.p.m.

19.10

Given:-

$V_o = 300\ cm^3$
$M_o = ?$
$n_o = 1$
$V_r = 14.7\ cm^3$
$M_r = 0.02\ M$
$n_r = 4$

$O_2 \qquad S_2O_3^{2-}$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_r}{n_r}$$

$$\frac{300 \times M_o}{1} = \frac{14.7 \times 0.02}{4}$$

$$\Rightarrow M_o = \frac{14.7 \times 0.02}{4 \times 300}$$

$= 2.45 \times 10^{-4}$ moles/L
$= 2.45 \times 10^{-4} \times 32$ g/L (Rel molecular mass $O_2 = 32$)
$= 7.84 \times 10^{-3}$ g/L
$= 7.84 \times 10^{-3} \times 1000$ mg/L
$= 7.84$ mg/L
$= 7.84$ p.p.m.

After 5 days

Given:-

$V_o = 300\ cm^3$
$M_o = ?$
$n_o = 1$
$V_r = 4.8\ cm^3$
$M_r = 0.02\ M$
$n_r = 4$

$O_2 \qquad S_2O_3^{2-}$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_r}{n_r}$$

$$\frac{300 \times M_o}{1} = \frac{4.8 \times 0.02}{4}$$

$$\Rightarrow M_o = \frac{4.8 \times 0.02}{4 \times 300}$$

$= 8 \times 10^{-5}$ moles/L
$= 8 \times 10^{-5} \times 32$ g/L (Rel molecular mass $O_2 = 32$)
$= 2.56 \times 10^{-3}$ g/L
$= 2.56 \times 10^{-3} \times 1000$ mg/L
$= 2.56$ mg/L
$= 2.56$ p.p.m.

B.O.D. in diluted sample = 7.84 – 2.56 = 5.28
But since the original water sample was diluted twenty times
$\Rightarrow$ B.O.D. of original water sample = $5.28 \times 20 = 105.6$ p.p.m.

Answer: B.O.D.= 105.6 p.p.m.

Chapter 21 – Fuels and Heats of Reaction

21.12
Mass of solution = 500 g = 0.5 kg
Temperature rise = 18.2 – 14.8 = 3.4 °C
Specific heat capacity = 4,060 J kg^{-1} K^{-1}

Heat liberated = mass × specific heat capacity × temp. rise
= 0.5 × 4,060 × 3.4
= 6,902 J

$$\text{Number of moles of HCl neutralised} = \frac{\text{volume} \times \text{molarity}}{1000} = \frac{250 \times 0.5}{1000} = 0.125$$

i.e. 0.125 mole HCl neutralised liberates 6,902 J

$$\Rightarrow \quad \text{1 mole HCl neutralised liberates } \frac{6{,}902}{0.125} = 55{,}216 \text{ J}$$

Since for HCl, 1 mole of acid gives 1 mole of H^+ ions
∴ Heat of neutralisation = - 55.216 kJ mol^{-1}
i.e. HCl + NaOH ——> NaCl + H_2O ΔH = - 55.216 kJ mol^{-1}

Answer: Heat of neutralisation = - 55.216 kJ mol^{-1}

21.13
Mass of solution = 200 g = 0.2 kg
Temperature rise = 6.8 °C
Specific heat capacity = 4,200 J kg^{-1} K^{-1}

Heat liberated = mass × specific heat capacity × temp. rise
= 0.2 × 4,200 × 6.8
= 5,712 J

$$\text{Number of moles of } H_2SO_4 \text{ neutralised} = \frac{\text{volume} \times \text{molarity}}{1000} = \frac{100 \times 0.5}{1000} = 0.05$$

i.e. 0.05 mole H_2SO_4 neutralised liberates 5,712 J

$$\Rightarrow \quad \text{1 mole } H_2SO_4 \text{ neutralised liberates } \frac{5{,}712}{0.05} = 114{,}240 \text{ J}$$

= 114.24 kJ

i.e. H_2SO_4 + 2NaOH ——> Na_2SO_4 + $2H_2O$ ΔH = - 57.12 kJ mol^{-1}
$2H^+ + 2OH^-$ ——> $2H_2O$
Since, by definition, heat of neutralisation involves just 1 mole of H^+ ions reacting with 1 mole of OH^- ions to form 1 mole of H_2O

$\Rightarrow$ Heat of neutralisation $= \dfrac{-114.24}{2} = -57.12$ k J mol^{-1} $\Delta H = -57.12$ kJ mol^{-1}

Answer: Heat of neutralisation = -57.12 kJ mol^{-1}

21.14

Heat of neutralisation = - 57. 2 k J mol^{-1} i.e. 1 mole HCl neutralised liberates 57,200 J

Number of moles of HCl neutralised $= \dfrac{\text{volume} \times \text{molarity}}{1000} = \dfrac{50 \times 1}{1000} = 0.05$

$\Rightarrow$ 0.05 mole HCl neutralised liberates $0.05 \times 57{,}200 = 2{,}860$ J

Mass of solution = 100 g = 0.1 kg
Temperature rise = ?
Specific heat capacity = 4,200 J kg^{-1} K
Heat liberated = 2,860 J

Heat liberated = mass × specific heat capacity × temp. rise

$\Rightarrow$ Temp. rise $= \dfrac{\text{Heat liberated}}{\text{mass} \times \text{specific heat capacity}}$

$= \dfrac{2{,}860}{0.1 \times 4{,}200} = 6.81$ °C

Answer: Temperature rise = 6.81 °C

21.15

Required Equation: $2C_{(s)} + 3H_{2\,(g)} \longrightarrow C_2H_{6\,(g)}$ $\Delta H = ?$

(a) × 2 $2C_{(s)} + O_{2\,(g)} \longrightarrow 2CO_{2\,(g)}$ $\Delta H = -787$ kJ mol^{-1}
(b) × 3 $3H_{2\,(g)} + 1\tfrac{1}{2}O_{2\,(g)} \longrightarrow 3H_2O_{(g)}$ $\Delta H = -857.4$ kJ mol^{-1}
(c) reversed × ½ $2CO_{2\,(g)} + 3H_2O_{(g)} \longrightarrow C_2H_{6\,(g)} + 3\tfrac{1}{2}O_{2\,(g)}$ $\Delta H = 1{,}559.8$ kJ mol^{-1}

$2C_{(s)} + \cancel{O_{2\,(g)}} + 3H_{2\,(g)} + \cancel{1\tfrac{1}{2}O_{2\,(g)}} + \cancel{2CO_{2\,(g)}} + \cancel{3H_2O_{(g)}} \longrightarrow \cancel{2CO_{2\,(g)}} + \cancel{3H_2O_{(g)}} + C_2H_{6\,(g)} + \cancel{3\tfrac{1}{2}O_{2\,(g)}}$

i.e. $2C_{(s)} + 3H_{2\,(g)} \longrightarrow C_2H_{6\,(g)}$ $\Delta H = -84.6$ kJ mol^{-1}

Answer: $\Delta H = -84.6$ kJ mol^{-1}

21.16

Required Equation:- $HCOOH_{(l)} \longrightarrow CO_{(g)} + H_2O_{(l)}$ $\Delta H = ?$

(a) $C_{(s)} + \frac{1}{2}O_{2(g)} \longrightarrow CO_{(g)}$ $\Delta H = -111\ kJ\ mol^{-1}$

(b) $H_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \longrightarrow H_2O_{(l)}$ $\Delta H = -285.8\ kJ\ mol^{-1}$

(c) reversed $HCOOH_{(l)} \longrightarrow H_{2\,(g)} + O_{2\,(g)} + C_{(s)}$ $\Delta H = 424.7\ kJ\ mol^{-1}$

$\cancel{C_{(s)}} + \cancel{\frac{1}{2}O_{2\,(g)}} + \cancel{H_{2\,(g)}} + \cancel{O\frac{1}{2}_{2\,(g)}} + HCOOH_{(l)} \longrightarrow CO_{(g)} + H_2O_{(l)}\ \cancel{H_{2\,(g)}} + \cancel{O_{2\,(g)}} + \cancel{C_{(s)}}$

i.e. $HCOOH_{(l)} \longrightarrow CO_{(g)} + H_2O_{(l)}$ $\Delta H = 27.9\ kJ\ mol^{-1}$

Answer: $\Delta H = 27.9\ kJ\ mol^{-1}$

21.17

Required Equation :- $C_{(s)} + \frac{1}{2}O_{2\,(g)} \longrightarrow CO_{(g)}$ $\Delta H = ?$

(a) $C_{(s)} + O_{2\,(g)} \longrightarrow CO_{2\,(g)}$ $\Delta H = -393\ kJ\ mol^{-1}$

(b) reversed × ½ $CO_{2\,(g)} \longrightarrow CO_{(g)} + \frac{1}{2}O_{2\,(g)}$ $\Delta H = 285\ kJ\ mol^{-1}$

$C_{(s)} + O_{2\,(g)} + \cancel{CO_{2\,(g)}} \longrightarrow \cancel{CO_{2\,(g)}} + CO_{(g)} + \frac{1}{2}O_{2\,(g)}$

i.e. $C_{(s)} + \frac{1}{2}O_{2\,(g)} \longrightarrow CO_{(g)}$ $\Delta H = -108\ kJ\ mol^{-1}$

Required Equation :- $\frac{1}{2}N_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \longrightarrow NO_{(g)}$ $\Delta H = ?$

(c) × ½ $\frac{1}{2}N_{2\,(g)} + O_{2\,(g)} \longrightarrow NO_{2\,(g)}$ $\Delta H = 33\ kJ\ mol^{-1}$

(d) reversed × ½ $NO_{2\,(g)} \longrightarrow NO_{(g)} + \frac{1}{2}O_{2\,(g)}$ $\Delta H = 57\ kJ\ mol^{-1}$

$\frac{1}{2}N_{2\,(g)} + O_{2\,(g)} + \cancel{NO_{2\,(g)}} \longrightarrow \cancel{NO_{2(g)}} + NO_{(g)} + \frac{1}{2}O_{2\,(g)}$

i.e. $\frac{1}{2}N_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \longrightarrow NO_{(g)}$ $\Delta H = 90\ kJ\ mol^{-1}$

Answer: Carbon monoxide: $\Delta H = -108\ kJ\ mol^{-1}$
Nitrogen monoxide: $\Delta H = 90\ kJ\ mol^{-1}$

Chapter 24 - Stoichiometry II

24.1

Relative molecular mass $C_6H_{12}O_6$ = 6(12) + 12(1) + 6(16) =180
Relative molecular mass C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46

$$\text{Number of moles of } C_6H_{12}O_6 = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{20}{180} = 0.11$$

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$
1 mole $\longrightarrow$ 2 moles
$\Rightarrow$0.11 mole $\longrightarrow$ 0.11×2 mole
= 0.22 mole
= 0.22×46
= 10.12 g
i.e. the theoretical yield of ethanol is 10.12 g

$$\text{Percentage yield} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{7.5}{10.12} \times 100$$

= 74.11%

Answer: Percentage yield of ethanol is 74.11%.

24.2

Assume ethanol is the limiting reagent.
Relative molecular mass C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46
Relative molecular mass $CH_3COOC_2H_5$ = 12 + 3(1) + 12 + 2(16) + 2(12) + 5(1) = 88

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{21}{46} = 0.46$$

$CH_3COOH + C_2H_5OH \longrightarrow CH_3COOC_2H_5 + H_2O$
1 mole $\longrightarrow$ 1 mole
$\Rightarrow$ 0.46 moles $\longrightarrow$ 0.46 moles
= 0.46×88
= 40.48 g
i.e. the theoretical yield of ethyl ethanoate is 40.48 g

$$\text{Percentage yield} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{20}{40.48} \times 100$$

$= 49.41\%$

Answer: Percentage yield of ethyl ethanoate is 49% (to nearest whole number)

<u>24.3</u>

(i) Relative molecular mass C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46

Relative molecular mass $Na_2Cr_2O_7.2H_2O$ = 2(23) + 2(52) + 7(16) + 2(18) = 298

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{11.04}{46} = 0.24$$

$$\text{Number of moles of sodium dichromate} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{17.88}{298} = 0.06$$

$$3C_2H_5OH + Cr_2O_7^{2-} + 8H^+ \longrightarrow 3CH_3CHO + 2Cr^{3+} + 7H_2O$$

3 moles — 1 mole

$\Rightarrow 0.06 \times 3$ mole — 0.06 mole

= 0.18 mole

0.18 mole of ethanol would react with 0.06 mole of dichromate. However, there is 0.24 mole of ethanol present, i.e. the ethanol is present in excess.

(ii) Rel molecular mass mass CH_3CHO = 12 + 3(1) + 12 + 1+ 16 = 44

The dichromate is the limiting reactant, so we calculate the percentage yield of ethanal on the amount of dichromate present.

$$3C_2H_5OH + Cr_2O_7^{2-} + 8H^+ \longrightarrow 3CH_3CHO + 2Cr^{3+} + 7H_2O$$

1 mole $\longrightarrow$ 3 moles

$\Rightarrow$ 0.06mole $\longrightarrow$ 0.06×3 mole

= 0.18 mole

$= 0.18 \times 44$

= 7.92 g

i.e. the theoretical yield of ethanal is 7.92 g

$$\text{Percentage yield} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{2.97}{7.92} \times 100$$

$= 37.5\%$

Answer: (i) The ethanol is in excess.

(ii) Percentage yield of ethanal is 37.5%.

24.4

(i) Relative molecular mass $Na_2Cr_2O_7.2H_2O = 2(23) + 2(52) + 7(16) + 2(18) = 298$
Relative molecular mass $C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46$

$$\text{Number of moles of sodium dichromate} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{29.8}{298} = 0.1$$

Mass of ethanol = Density × Volume = 0.8 × 6.9 = 5.52 g

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{5.52}{46} = 0.12$$

$$3C_2H_5OH + 2Cr_2O_7^{2-} + 16H^+ \longrightarrow 4Cr^{3+} + 3CH_3COOH + 11H_2O$$

3 moles 2 moles

i.e. 1 mole of ethanol reacts with $^2/_3$ mole of dichromate.

⇒ 0.12 mole of ethanol reacts with $^2/_3 \times 0.12 = 0.08$ mole of dichromate

i.e. 0.08 mole of dichromate would react with 0.12 mole of ethanol. However, there is 0.1 mole of dichromate present. Therefore, the dichromate is present in excess.

(ii) Relative molecular mass $CH_3COOH = 12 + 3(1) + 12 + 2(16) + 1 = 60$
The ethanol is the limiting reactant, so we calculate the percentage yield of ethanoic acid on the amount of ethanol present.

$$3C_2H_5OH + 2Cr_2O_7^{2-} + 16H^+ \longrightarrow 4Cr^{3+} + 3CH_3COOH + 11H_2O$$

3 moles ⟶ 3 moles
⇒ 0.12 moles ⟶ 0.12 moles
= 0.12 × 60
= 7.2 g

i.e. the theoretical mass of ethanoic acid is 7.2 g

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

⇒Mass = Density × Volume
= 1.06 × 5.4 = 5.724 g (actual mass of ethanoic acid)

$$\text{Percentage yield} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{5.724}{7.2} \times 100$$

$$= 79.5\%$$

Answer : (i) The sodium dichromate is in excess.
(ii) Percentage yield of ethanoic acid is 79.5%.

24.5

Relative molecular mass Fe_2O_3 = 2(56) + 3(16) = 160
Relative atomic mass C = 12
Relative atomic mass Fe = 56

$$\text{Number of moles of iron (III) oxide} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{500}{160} = 3.125$$

$$\text{Number of moles of carbon} = \frac{\text{Mass}}{\text{Rel atomic mass}} = \frac{50}{12} = 4.167$$

$$2Fe_2O_3 + 3C \longrightarrow 3CO_2 + 4Fe$$

2 moles　　3 moles
$\Rightarrow$ $4.167 \times {}^2/_3$ moles　　4.167 moles
= 2.778 moles

2.778 moles of iron (III) oxide would react with 4.167 moles of carbon. However, there is 3.125 moles of iron (III) oxide present, i.e. the iron (III) oxide is present in excess.

The carbon is the limiting reactant, so we calculate the maximum mass of iron obtainable on the amount of carbon present.

$$2Fe_2O_3 + 3C \longrightarrow 3CO_2 + 4Fe$$

3 moles $\longrightarrow$ 4 moles
$\Rightarrow$ 4.167 moles $\longrightarrow$ $4.167 \times 1{}^1/_3$ moles
= 5.556 moles
= 5.556×56
= 311 g (theoretical mass of iron)

$\Rightarrow$ Maximum mass of iron produced = 311 g

Answer: Maximum mass of iron obtainable = 311g .

24.6

(a) Calculation of percentage yield of ethanal

Relative molecular mass $Na_2Cr_2O_7.2H_2O$ = 2(23) + 2(52) + 7(16) + 2(18) = 298

Relative molecular mass C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46

Relative molecular mass CH_3CHO = 12 + 3(1) + 12 + 1 +16 = 44

$$\text{Number of moles of sodium dichromate} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{8.94}{298} = 0.03$$

Mass of ethanol = Density × Volume = 0.8 × 6.9 = 5.52 g

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{5.52}{46} = 0.12$$

$3C_2H_5OH$	+	$Cr_2O_7^{2-}$	+ $8H^+ \longrightarrow 3CH_3CHO + 2Cr^{3+} + 7H_2O$
3 moles		1 mole	
0.09 mole		0.03 mole	

From the balanced equation, 1 mole of dichromate reacts with 3 moles of ethanol. Therefore, 0.03 mole of dichromate would react with 3 × 0.03 = 0.09 mole of ethanol.

However, there is 0.12 mole of ethanol present, i.e. the ethanol is present in excess. In other words, the sodium dichromate is present in limiting amount.

Since the sodium dichromate is the limiting reactant, we calculate the percentage yield of ethanal on the amount of sodium dichromate present.

$$3C_2H_5OH + Cr_2O_7^{2-} + 8H^+ \longrightarrow 3CH_3CHO + 2Cr^{3+} + 7H_2O$$

1 mole ⟶ 3 moles

⇒ 0.03 mole ⟶ 0.03 × 3 mole

= 0.09 mole

= 0.09 × 44

= 3.96 g

i.e. the theoretical yield of ethanal is 3.96 g

$$\text{Percentage yield of ethanal} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{1.62}{3.96} \times 100$$

$$= 40.91\%$$

(b) Calculation of percentage yield of ethanoic acid
Relative molecular mass C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46
Relative molecular mass CH_3COOH = 12 + 3(1) +12 + 2(16) +1 = 60

Mass of ethanol = Density × Volume = 0.8 × 2.3 = 1.84 g

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{1.84}{46} = 0.04$$

Number of moles of sodium dichromate [as calculated in part (a)] = 0.03

$$3C_2H_5OH + 2Cr_2O_7^{2-} + 16H^+ \longrightarrow 4Cr^{3+} + 3CH_3COOH + 11H_2O$$

3 moles 2 moles

i.e. 1 mole of ethanol reacts with $^2/_3$ mole of dichromate
Therefore, 0.04 mole of ethanol reacts with $^2/_3 \times 0.04 = 0.027$ mole of dichromate
i.e. 0.04 mole of ethanol would react with 0.027 mole of dichromate.

However, there is 0.03 mole of dichromate present. Therefore, the dichromate is present in excess, i.e. the ethanol is the limiting reactant.

Since the ethanol is the limiting reactant, we calculate the percentage yield of ethanoic acid on the amount of ethanol present.

$$3C_2H_5OH + 2Cr_2O_7^{2-} + 16H^+ \longrightarrow 4Cr^{3+} + 3CH_3COOH + 11H_2O$$

3 moles ⟶ 3 moles
⇒ 0.04 mole ⟶ 0.04 mole
= 0.04 × 60
= 2.4 g

i.e. the theoretical yield of ethanoic acid is 2.4 g

$$\text{Percentage yield of ethanoic acid} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{1.73}{2.4} \times 100$$

$$= 72.08\%$$

Answer : (a) Percentage yield of ethanal is 40.91%.
(b) Percentage yield of ethanoic acid is 72.08%.